SEPIC

Support to Enhance Privatization, Investment, and Competitiveness in the Water Sector of the Romanian Economy

CURRENT APPLICATIONS OF DECISION SUPPORT SYSTEMS FOR INTEGRATED WATER MANAGEMENT IN ROMANIA

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Acronyms

AEWS – Accident Emergency Warning System
ANAR – National Administration “Apele Romane”
DA/ RBD – River Basin Directorate
DESWAT – Disaster Water project
DSS – Decision Support System
EU/ UE – European Union
GIS – Geographical Information System
HS/ SH – Hydrological Stations/ Service
INHGA – National Institute of Hydrology and Water Management
NATO – North Atlantic Treaties Organization
PIAC – Principal International Alert Centers
SEPIC – Support to Enhance Privation, Investment and Competitiveness in the Water Sector of the Romanian Economy
SGA – Water Management System
SIMIN – Meteorological Information System
TAIWAT – Trade and Investment for Water
UTCB – Technical University of Civil Engineering of Bucharest
WATMAN – Water Management Project
WFD – (EU) Water Framework Directive
WMS – Water Management System

Introduction

After the big floods of 1999-2003, water decision makers have become increasingly interested in Decision Support System (DSS) that allow to present in a synthetic and graphical form the alternative choices and the evaluation of the expected damages or benefits arising from their decisions in the field of flood management.

In the area of flood risk mitigation and control the present state of the art allows for the development of reliable rainfall-runoff models, but in general the forecast is strongly affected by the knowledge of the uncertainty about future rainfall. In addition, a wide gap exists not only between Meteorologists and Atmosphere Physicists on one side and Hydrologists, Soil Physicists and Engineers on the other side, but also between Scientists and Decision makers. A DSS for Romania in water management should cover the flood management issue including well-equipped basins regarding hydro-technical infrastructures but not only - water supply and spills are important aspects, too.

In the recent years additional issues were included in the field of water management in Romania regarding WFD implementation; consequently, decision makers in the field of integrated water management, have become increasingly interested in decision support systems that allow presenting in a synthetic and graphical form the alternative choices in river basin master-plan designing, in water supply during droughty periods or accidental spills, or in case of floods.

Therefore, to be of any practical value, the DSS including different procedures like expert systems or optimization methods must allow for simulation of alternative management policies under uncertain evolution of natural events (floods, droughts or accidental spills).

The main goal of DSS is to help water managers to formulate policy for river basin management and to take appropriate measures to achieve the policy objectives.

Decision Support Systems can be described and categorized from a variety of viewpoints. For our purpose we distinguish between two main groups of DSS, namely data oriented and model oriented DSS.

Data-oriented DSS was primarily developed under the ANAR dispatch application. Data–oriented DSS is concerned with retrieval, analysis and presentation of data.

Model-oriented DSS include activities such as simulation, goal-seeking and optimization. Although in Romania it is not operational any model-oriented DSS, there are some models regarding optimization procedures which were used separately, solving different problems regarding flood management or water supply.

The domain of integrated river basin management is concerned with understanding and acting upon a highly complex and dynamical system of interrelated physical and non-physical processes. The DSS provides a representation of this system in a form of an integral model.

Although data analysis and presentation are important functions of the DSS, the integrated water management system falls under the category of model-oriented DSS.

From institutional point of view, decision makers for water management in Romania are:
- Ministry of Environment and Water Management, responsible with policy and national strategy for water management and
- National Administration “Apele Romane” (ANAR), the planners and managers of water resource systems, who are responsible for solving water-related problems or meeting water resource needs.

The decisions are:
- Strategic, or/ and
- operational.

The objective of ANAR is, among other things:
- to provide the reliable supply of water with a quality appropriate for its use, including production of hydropower,
- protection from floods, and
- protection of ecosystems,
- economic analysis.

Integrated river management confronts the decision makers with numerous possible measures, as well as multiple, possibly conflicting, objectives. Together, these measures and objectives form the decision space, and the decision maker uses the simulation facilities provided by the DSS to explore and to navigate it.

A DSS can be distinguished from more straightforward engineering applications by its capability to address ill-defined problems. To achieve this, the DSS often features a knowledge engine that applies various artificial intelligence methods to a formal representation of expert knowledge from the problem domain.

This report draws the conditions in Romanian Water Management System to develop and use a DSS.
In this respect, different models and methodologies, designed interfaces for the operational activities developed in Romania will be presented. The final boot is to choose different applications to be included under the DSS for integrated water management in Romania and to use the local specialists’ knowledge for designing this application.

Thus, in the first chapter there will be presented different DSS conceptions developed in different projects:
- DSS for flood forecasting (AFORISM and MOSYM Projects),
- DSS for water management in an agriculture basin – nitrates and phosphates use was considered in an irrigated area, in connection with the water quality aspects inside the basin,
- DSS for water management taking into account the ecological dimension in the Delta of the Danube River.

In the second chapter, some hydraulic models are presented, as MIPE, UNDA, POTOP. The hydraulic models are presented in the context of generating risk maps, an important tool for flood preparedness in water management.

The third chapter is dedicated to the Romanian experience in using different water pollution models, on rivers and on groundwater.

Further on, a large package of models using different optimization algorithms are presented, for both water allocation optimization as well as for flood management.

I. Description of Decision Support Systems in Romania – experience of EC projects and Romanian applications

The operational needs of water managers from European and EU pre-accession countries have contributed to the demand for the DSS tools to assure the system's relevance to current and future water management practices in European catchments. This led to some EU funding projects in the 5th Framework Program as **AFORISM** "A Comprehensive Forecasting System for Flood Control Risk Mitigation and Control" or **MULINO** "Multi-sectoral Integrated and Operational decision Support System for Sustainable Use of Water Resources at Catchment Scale", and **TRANSCAT** "Integrated Water management of Trans-boundary Catchments". Some national research programs as German "Integrated Modeling and Decision-Making Analysis for Water Quality" or Polish "Decision Support System for flood control in trans-boundary Nysa Klodzka catchment" can be mentioned, bringing new ideas in DSS development aspects.

AFORISM has been conceived to provide an inter-comparison of different approaches in rainfall-runoff modeling and their use both for planning and real time flood forecasting and management, aimed to the mitigation of natural hazards. More, to integrate all the innovative technologies in an operational decision support tool for flood forecasting and flood impact analysis. This tool is based on an Expert System which was designed to give the alternative management scenarios. It will be analyzed and presented to the decision makers on the basis of a Geographical Information System (GIS).
AFORISM gave results in comparing a number of different models ranging from the extremely simplified event models, through the continuous lumped semi-distributed models to the complex distributed models, in view of their inclusion in the forecasting and flood management system and the possibility of improving the representation of catchment behavior.

The decision process for managing flood control structures requires that the Decision Maker analysis the different impacts or consequences that may result as an effect of his decisions. This can be done by providing the Decision Maker with a Decision Support tool that allows him to rank the different alternatives more than to find an "optimal strategy". For this purpose the Compromise Programming Method was analyzed.

G2 Expert System was used and the set of rules were defined using questionnaires for the Operational managers and the Civil Response. ***Operational managers*** were defined as those dealing with the physical infrastructure of flood control such as dam operations and pumping decision etc. ***Civil Response managers*** were defined as those responsible for reacting to a flood event once it has occurred by carrying out temporary works, organizing evacuations, attempting to minimize economic and social costs etc. The set of rules included under Expert System refers to flood management and more general quantity and quality management.

AFORISM has been used as a research study of a complex comprehensive tool to be developed in order to support both planning and forecasting. The following actions will be to capitalize on the extremely high interest expressed by the Authorities and to operationally implement the system at the scale of a basin. This would allow for a thorough experimentation of the possible benefits arising from its use. Finally, given the increasing interest of public in participating to decisions that involve the essential safety of life, it was sought essential to deeply analyze the socio-economical impact and the public acceptance of flood risk mitigation pre-defined plans as well as the implementation of flood warning dissemination schemes. These are in essence the objectives of a new round of research.

An application for Romania was presented by **MULINO-DSS**, an acronym for MULti-sectoral, INtegrated and Operational decision support system, a project financed by the European Commission that focuses on the sustainable use of water resources at the catchment scale. The purpose of the project is to provide an operational Decision Support System (DSS) to assist water authorities in the management of water resources, aiming at improving the quality of decision making and seeking to achieve a truly integrated approach to river basin management.

The **DPSIR** approach (**D**riving Forces-**P**ressures **S**tate **I**mpact **R**esponse) allows the user to conceptualize and structure the decision situation according to the cause-effect relationships, which describe the inherent environmental problem(s) from the perspective of the decision maker (DM). In the real world, after having detected a negative Impact which falls within their competences, DMs investigate the possible causes to identify possible actions: i.e. they proceed backwards from Impacts up to the identification of the most likely Driving Forces. This process leads the DM to the formalization of DPS chains, which provide a conceptual description of issues, relations and problems upon which future decisions could be based. This phase represents the start of the decision process, usually followed by the identification of suitable model(s) and the analysis of data in the context of the specific decision. The information collected is then organized in the form of indicators in tabular or geographical formats allocated to nodes of the DPS chains.

The DSS tool integrates models (hydrological, ecological, socio-economic,...) with multi-criteria decision methods in order to assist water authorities in the management of water resources, coping with real problems and issues arising from variegated and conflicting water uses and demands. Decisional cases are formalized as sets of alternative Response options, among which the decision maker chooses the best one on the basis of a common list of criteria extracted from indicator values (D, P, or S) provided by various data sources and in particular by model simulations implemented to estimate the expected effects on the catchment system of the various options under evaluation. The designed application in Romania refers at Bahlui Basin. The DSS concentrated to improve the water allocation process under different constraints (climate change including). The Scenario component of the tool (SCE) allows the end user to evaluate the decision process in reference to visions of possible future conditions. The selection of the most desirable decision is supported by a process of Multi-Criteria Analysis (MCA) which is applied to the alternatives generated through the DPSIR analysis. Hydrological models (HYD) run within or outside the DSS tool, make the integrated simulation of multi-sectoral water uses possible. Capabilities for geographic data handling and display (GIS) are embedded to support the management of spatial data and the interface with the MULINO-DSS and the users – figure 1.

This application refers mainly to an agriculture basin, with problems of nitrates and phosphate pollution in irrigated crops. The decision process refers to water management in the context of an optimal production. DPSIR offers a facility for choosing the best solution in water management to increase the water quality in an agriculture basin. This DSS structure is more dedicated to agriculture activity and less to day-to-day activity in water management from ANAR perspective.

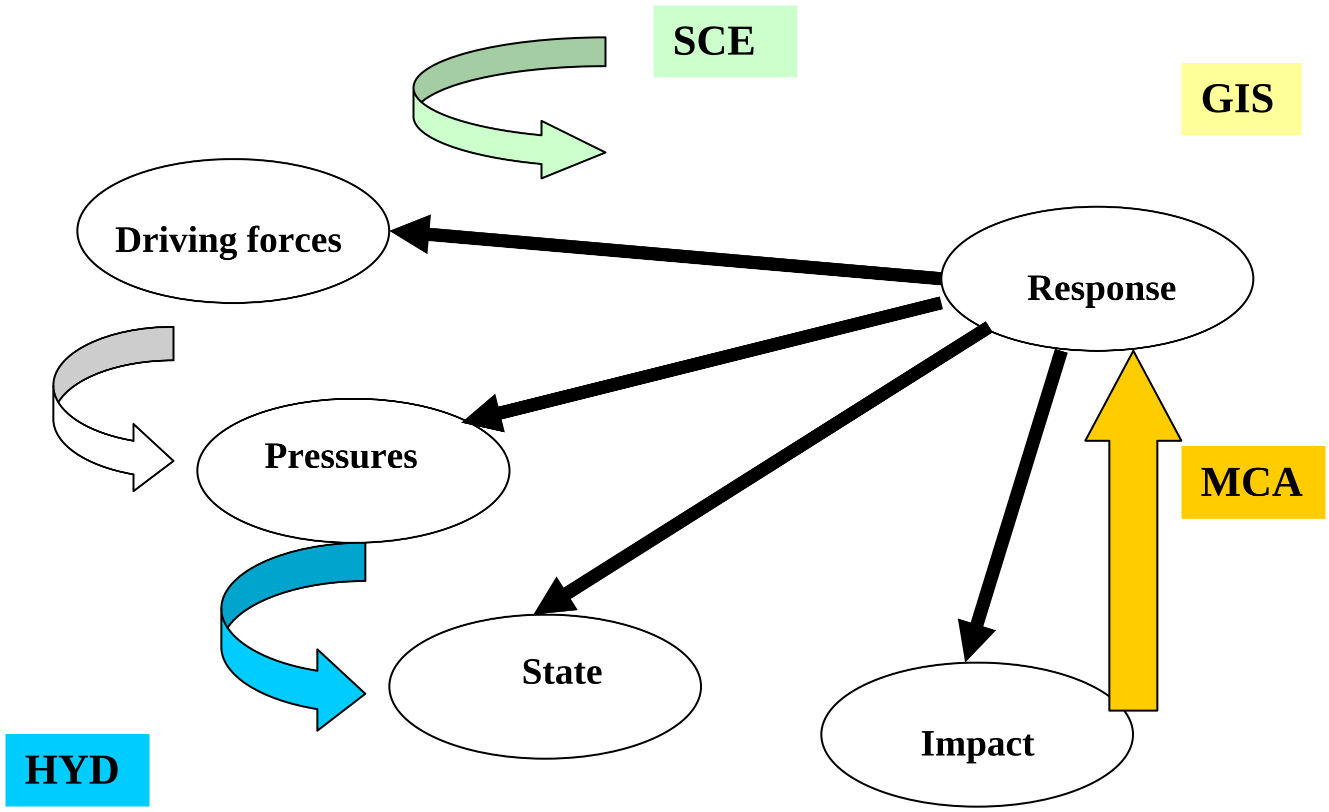

Figure 1. DSS for long term planning in water management – impact estimation

Fuzzy Expert System for Large Complex Environmental Problem- solving – a DSS for complex water management in the Danube Delta was developed, taking into account the ecological dimension. 10 large reservoirs connected through canals and channels were considered. The mathematical-heuristic model of an environmental system is a hybrid model composed of several mathematical models and heuristic models. A hybrid algorithm for simulation and control of the environmental system is presented. The simulation models are controlled by an expert system. The mathematical-heuristic model for simulation and control of dynamics of some populations of ichthyophagous birds (i.e. cormorants and pelicans) is also given. A knowledge base including behavioral control and decision heuristic rules was set-up. A model's library for environmental system simulations and control has been created. The block-diagram of the Expert System is presented in Figure 2.

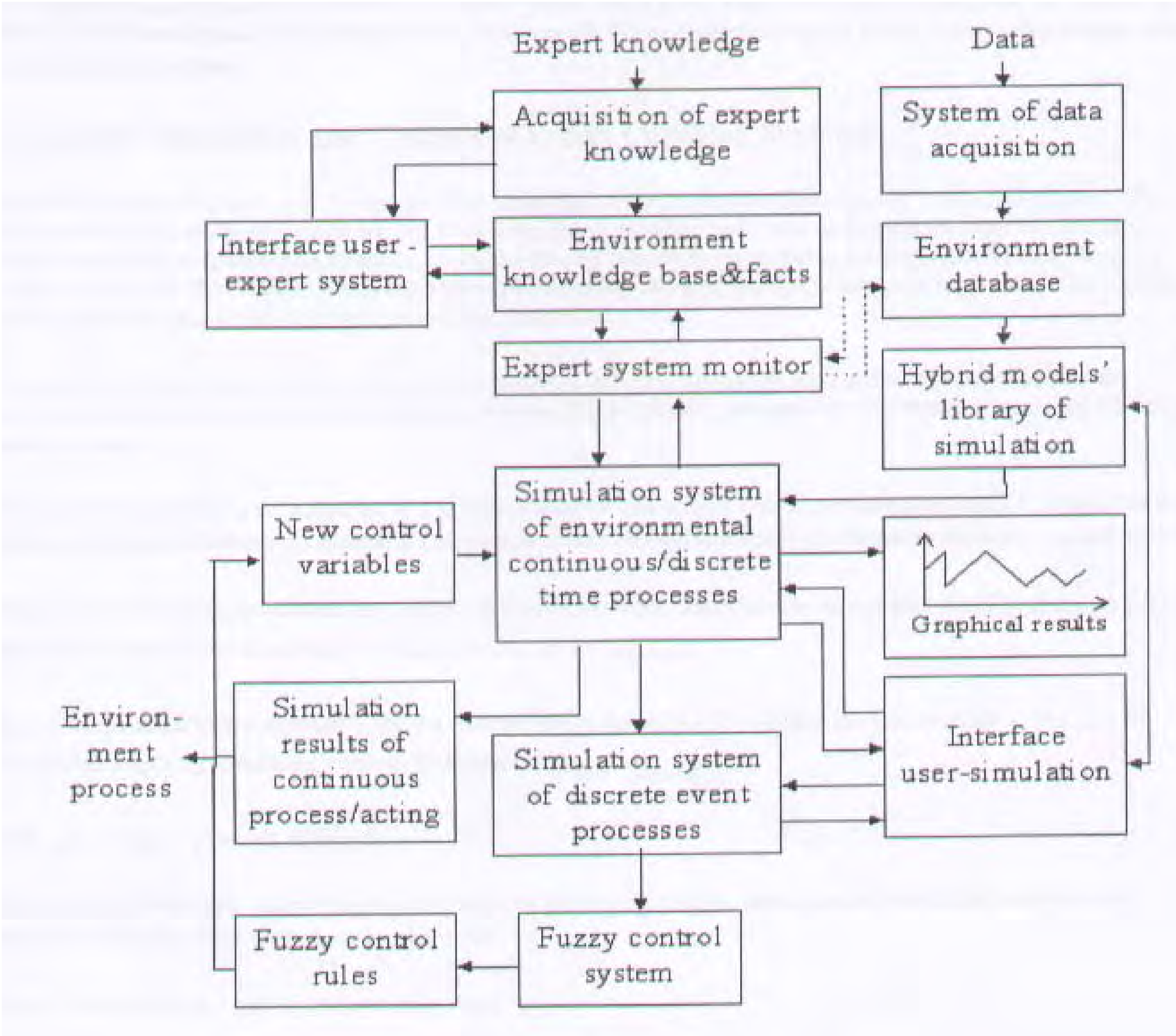

Figure 2. Expert system for integrated water management in the Danube Delta

This developed system is not operational because of the lack of data in continuous way. To become a real time application a new informational system for the Danube Delta (both for waters and environment) should be implemented. More, the application is not enough friendly; an interface with the data base, as well as with dispatch application for water management purposes should be developed.

Only one small DSS experiment created in EC ***MOSYM Project*** is functional at the moment, regarding flood forecasting and warning. In this project, it was used the VIDRA rainfall-runoff model.

VIDRA Model was first applied in the context of a DSS for flood management in MOSYM Project. The steps in applying the proposed VIDRA rainfall-runoff model are:

- The basin is divided into sub-basins according to a topological scheme of runoff formation and integration;
- For each sub-basin the snowmelt water is computed by use of the degree day method;
- The rainfall together with the snowmelt water (if applicable) are averaged over each sub-basin;
- Using a reservoir concept model of infiltration and evapo-transpiration the depth of effective rainfall (runoff) is determined over each sub-basin.
- Integration procedure making use of unit hydrograph is further applied to the runoff resulting in the flood discharge hydrographs of the sub-basins;
- The integration of the flood hydrographs in the nodes of the topological scheme, running and attenuation the flood along the river continuum.

The scheme of the runoff production subroutine of the flood-forecasting model VIDRA is given in Figure 3.

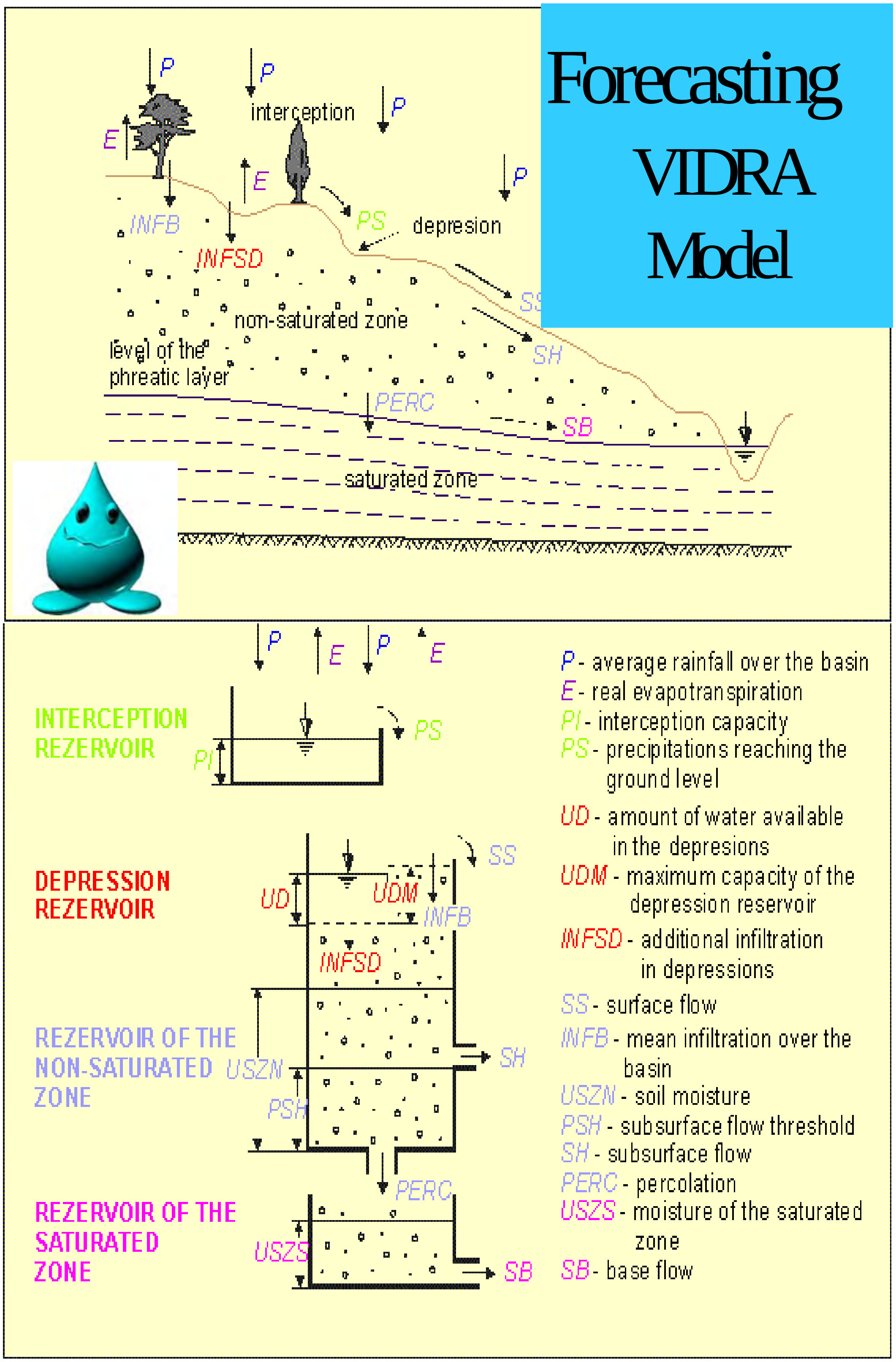

Figure 3. Description of the reservoirs of VIDRA Model

The complete sketch of the VIDRA flood-forecasting model is presented in Figure 4.

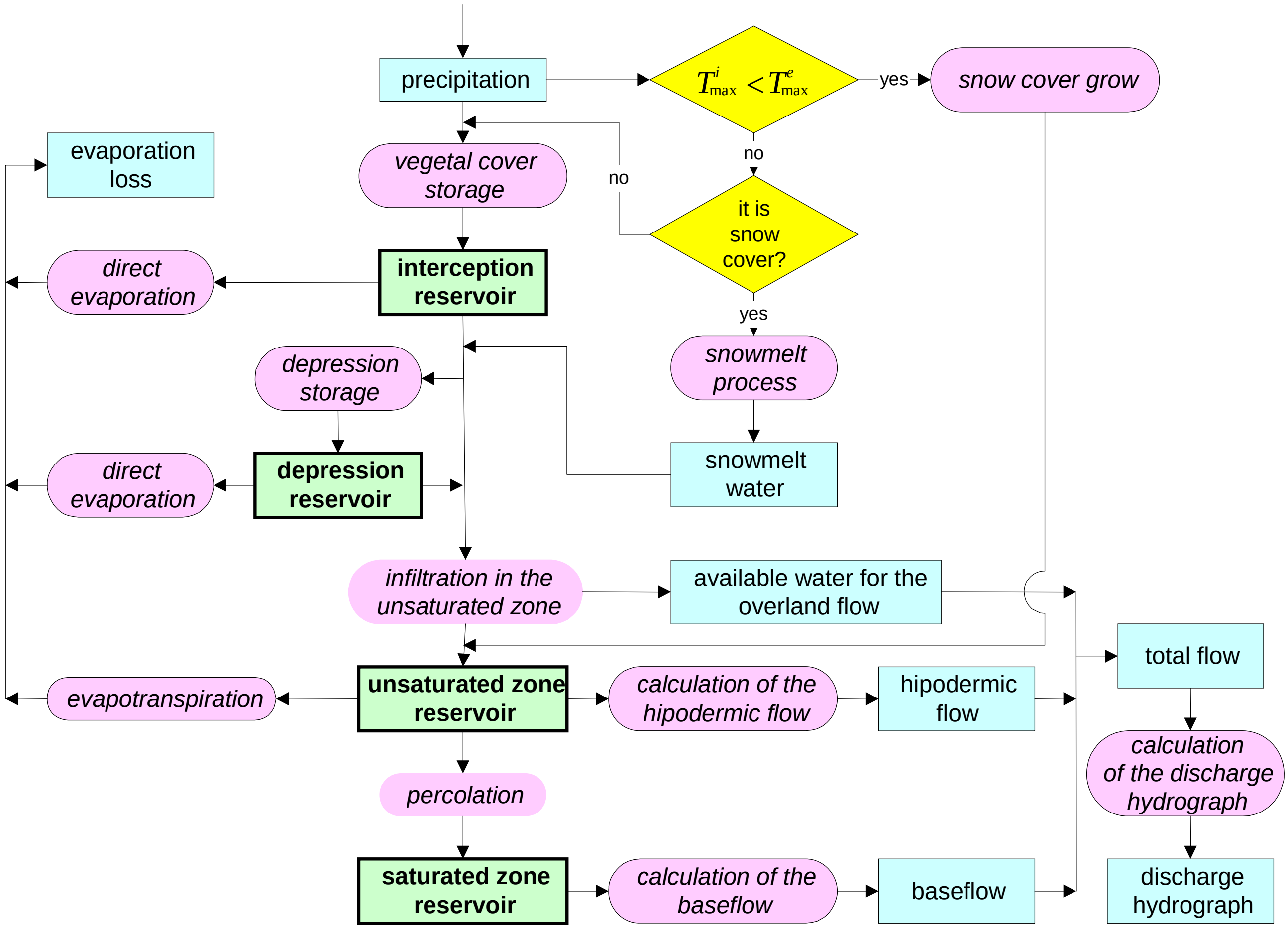

Figure 4. Sketch of the flood forecasting VIDRA Model

The parameters of VIDRA model have been determined for almost all the basins in Romania by the use of the regionalization relationships. Some relationships of the regionalization of VIDRA parameters are given as functions of the physiographical characteristics of the basin. Finally derived through a procedure of simulation the recorded floods and an optimization of the errors between the recorded floods and those simulated by model the best parameters for each basin are chosen. The model is the central piece of DESWAT project, regarding hydrological forecasting procedures developed in Romania.

An example of application of the flood-forecasting model is given in Figure 5. Here is a nice application between out put data from VIDRA Model, data coming from different gauging stations (operational data base) and cartography of the river network and gauging station on the rivers. We are looking further in developing such applications in the DSS for ANAR.

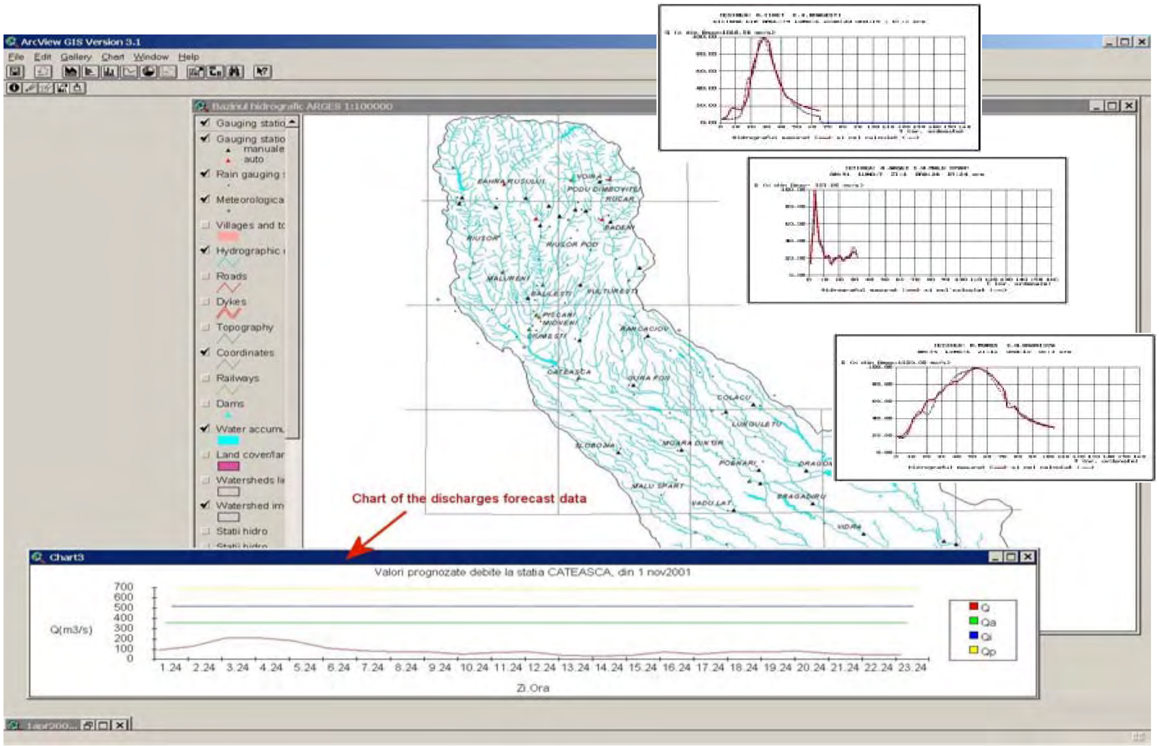

Figure 5. Application of the flood forecasting VIDRA Model.

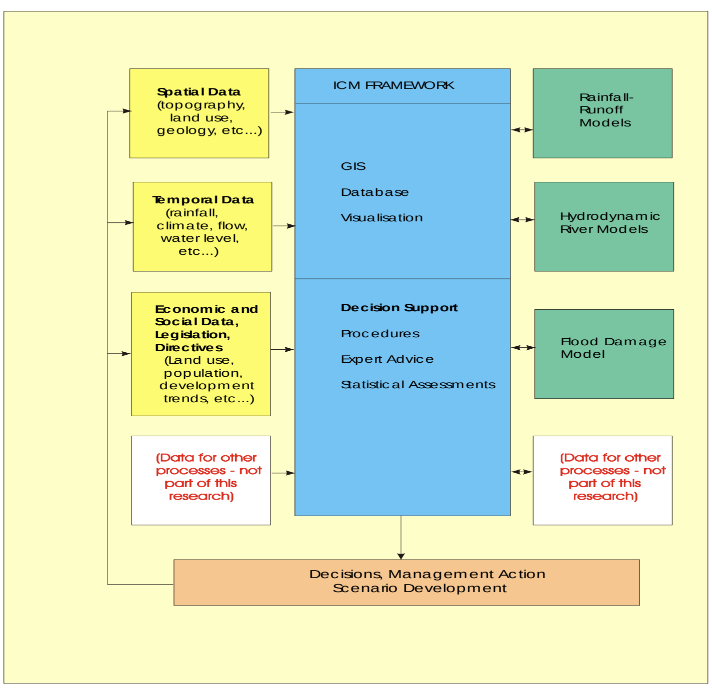

Figure 6. MOSYM DSS

The Decision-Making Support System for MOSYM Project consists in all final products of the actions undertaken until now. The component products are presented in the following schema of Figure 6. More, the information bulletins on the present situation of the water levels, precipitation and air temperature as well as on the water quality descriptors which are transmitted on-line from the already installed automatic stations, together with the forecasted values (the Figure 7).

For the visualization to the end users of the hydrological diagnosis and forecast the 1.1 version of the computer program PROGRESS VIEW was developed (Figure 8).

This computer program permits a quick visualization to the end users, both in numerical and graphical form (see the next figure), of the levels and discharges; diagnosis and forecast with 7 days lead time at the chosen sections situated in the pilot basins are prepared. The input data in the computer program PROGRESS VIEW (the outputs of the hydrological forecast model) are delivered to the end users through Internet (FTP protocol).

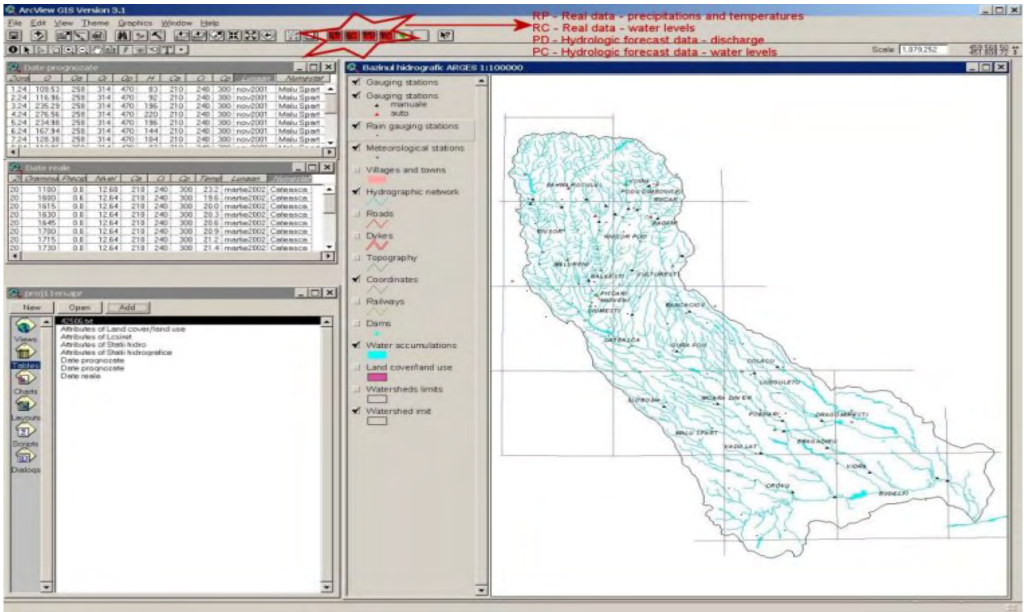

Figure 7. Data base DSS

An example for the Mures River is presented in the Figure 8.

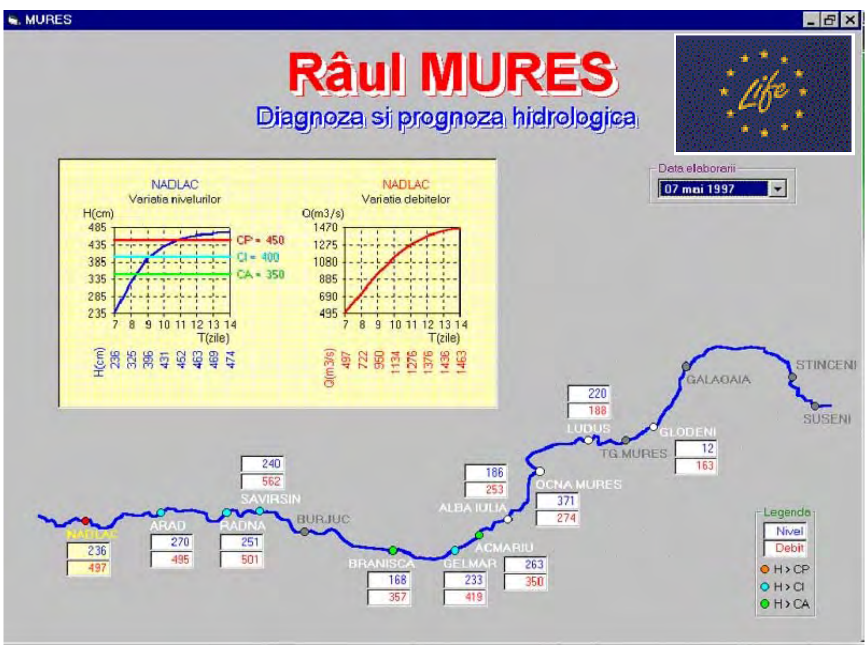

Figure 8. Real time Decision-Making Support System (Mures Basin application)

Dissemination action was the main task of DSS for flood management and planning friendly interfaces in this respect. Presentation of the data flux of the information system for flood warning and forecasting, is presented in the figure 9.

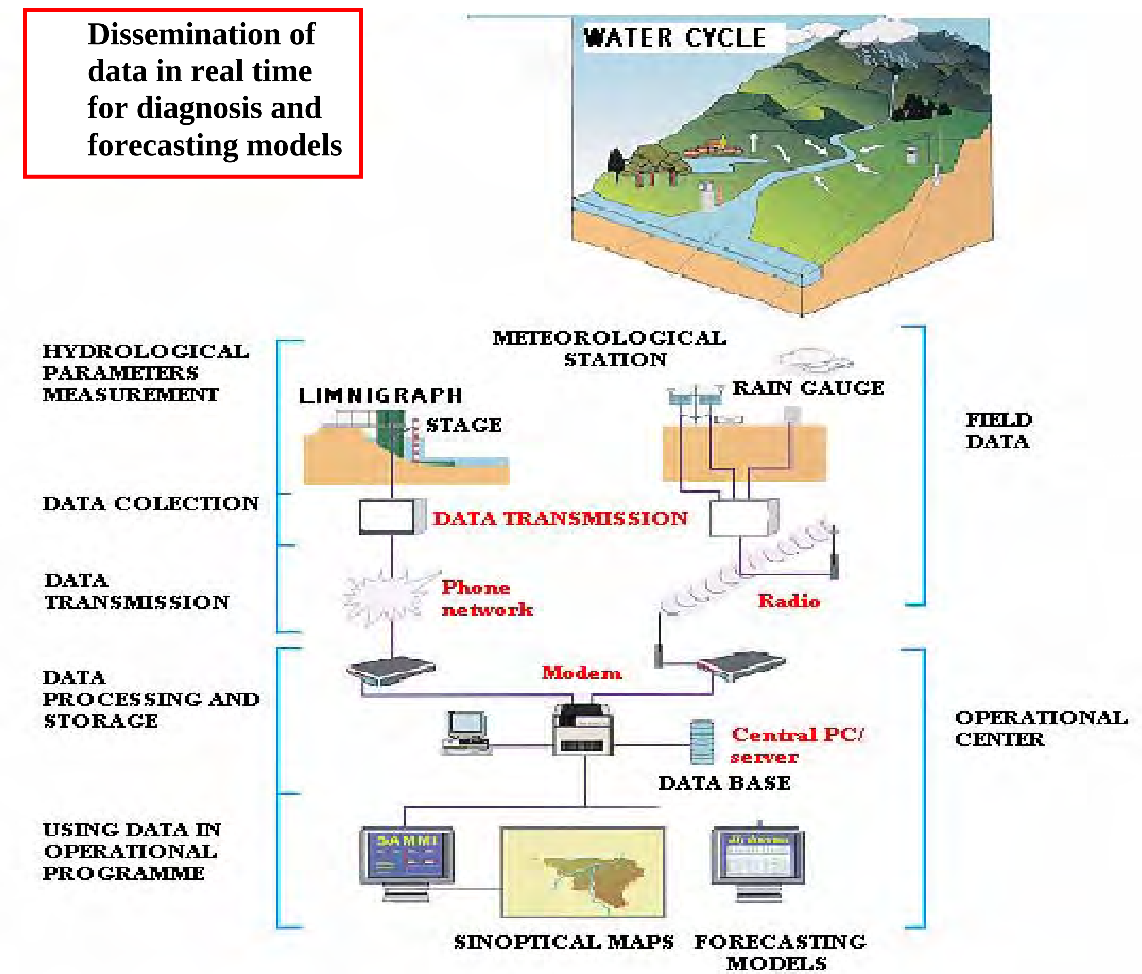

Figure 9. Data dissemination for MOSYM automatic system (HYDRAROM stations included)

A special INTERNET site (life-mosym.inmh.ro) that is linked with the INHGA INTERNET page presents some more details about the MOSYM Project.
The conception of flood forecasting DSS developed under MOSYM Project would be useful to be taken into account in further designing DSS for Romania.

To complete the design of DSS for integrated water management, other applications as flood forecasting need to be added, as hydraulic modeling of different types of hydro-technical water works and dam breaks simulation (flood management and flood preparedness planning), as well as different optimization models for water allocation for different river regime phases (low and medium flows and high flows).

II. Hydraulic Models and risk maps generating

MIPE model makes the numerical integration of the Bernoulli equation written for one dimensional stream with free surface, which results in the assessment of the rating curves in the lent gradual variate motion, in several cross sections of a river course from downstream to upstream. The results are presented both in tables and as graphs of the river surface line along the river course.

If along the considered river, there are dams or hydraulic works which narrow the riverbed, the motion equation changes its structure and in this case the riverbed is shared in several reaches so that the deemed water works should be found at the downstream end of each reach. The implicit motion equation is the weir formula applicable for at most three successive weirs or, according to the case, an imposed rating curve.

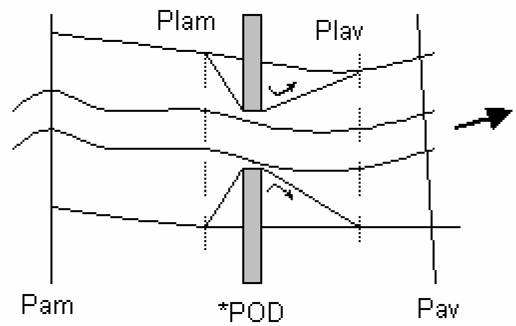

Figure 10.

The narrowing induced by the bridges is considered as cross sections which are specially marked so that the program interpolates the curves (60^o upstream and 30^o downstream) aiming to eliminating the whirlpools (Figure 10).

The computations are simultaneously made for eight discharges, starting from downstream to upstream. Along a reach the changes in the discharges are allowed due to the inputs of the tributaries. The motion equation are integrated with all terms as long as the Froude number is kept less than one, otherwise (as a rule for slopes greater than 1%) the motion equation is simplified, keeping only the friction terms.

The calibration of the model is made on the basis of the known rating curves at the gauging stations and the number and the precision of these curves significantly influence its accuracy. Very useful are the water levels recorded during floods in several sections along the river (especially at the bridge sections). Also, the hydro - topographic works are of interest in view of deriving the corresponding discharges from the closest cross sections where reliable rating curves are available.

The adjustment of the model is performed through:

- the roughness coefficients in the minor and major riverbeds,
- the modeling of the bank flooding,
- the factor of recovering the kinetic energy in the case of the riverbeds with important longitudinal line variation,
- the corresponding differentiation of the kilometer location of the minor and major riverbeds or even through the correction of the cross sections.

The results are presented in form of tables for each river reach and each considered discharge and they consist in:

- The level of line of the deepest depths
- The water level
- The breadths of the riverbed
- The areas of the active cross sections
- The velocities in the minor and major riverbed

The Froude number (an excerpt is given in Figure 11).

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CRISUL NEGRU NATURAL CU PRAG AV P45COTE Z(M)
LATIMI B(M) ARII A(M2) Vmin V1(M/S)
Vmaj V2 (M/S) PASUL DE CALCUL DX= 20.0 FRE=0
*******************************************
            ASIG=   10%      5%      1%
   NUME      X   Q=  525.0   630.0   890.0
*******************************************
    P37   1280.
     Z0=   95.11 Z= 103.04  103.57  104.87
                 B=   140.   154.0   163.0
                 A=   509.    586.    793.
                V1=   1.22    1.31    1.41
                V2=    .43     .48     .61
              FRGL=    .03     .03     .03
    P38   2015.
     Z0=   95.43 Z= 103.24  103.77  105.07
                 B=   168.   171.4   180.3
                 A=   636.    726.    953.
                V1=   1.10    1.18    1.31
                V2=    .39     .45     .54
Fig. 11        FRGL=    .02     .02     .02
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The water levels are graphically presented as a longitudinal profile of the free surface (Figure12) or as an image of cross profiles (Figure 13).

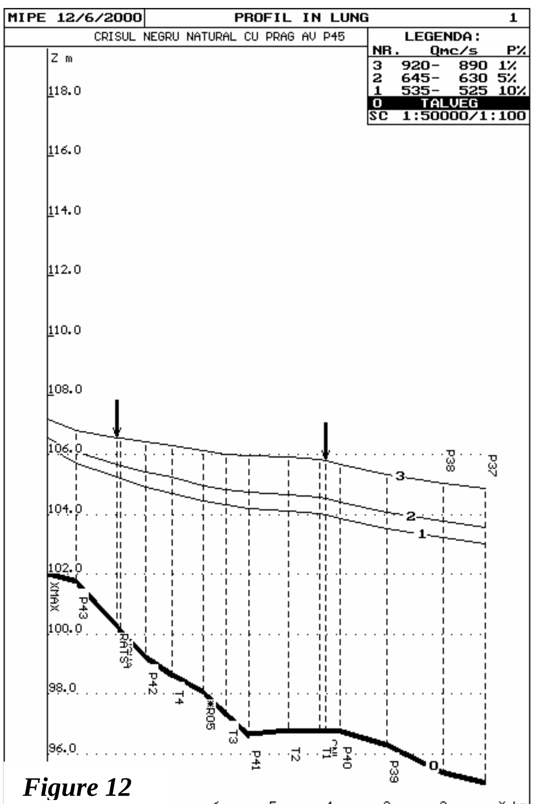


Figure 12

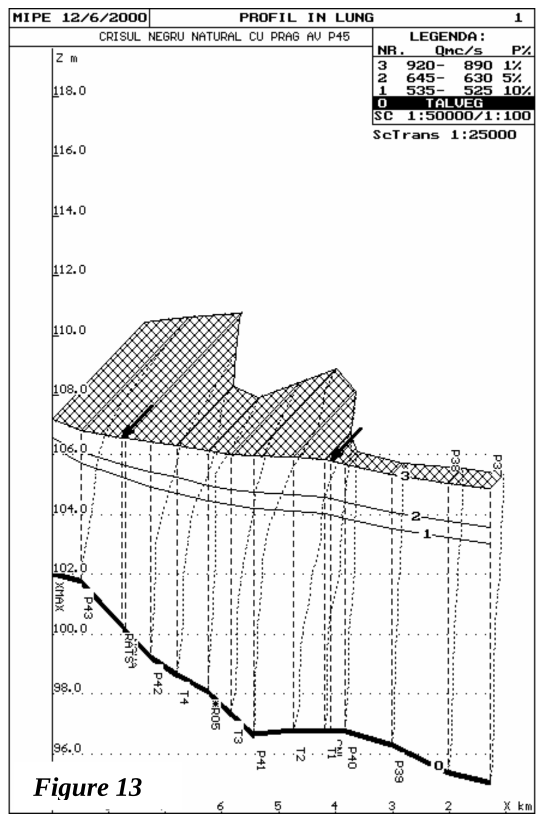


Figure 13

The UNDA model simulates the one-dimensional, unsteady flows with free surface. It is based on the system of Saint Venant equations, numerically integrated in finite differentials on a rectangular network in the plane X, T, in an implicit scheme with the linearization of the equations. The initial condition is considered a steady flow. Usually - the base discharge of the flood, while the standard border conditions are the input hydrographs and the rating curve in the final cross section – Figure 14.

An example for the calibration for Arges Basin, involving the use of 22 cross sections, out of which 7 are located at the road or railway bridges, distributed at a distance of 1km, is as follows: four sections on Argesel River, five on Targului and 13 on Doamnei River. Nine cross profiles (M1-M9) encompassing the non-permanent reservoir Maracineni (located at confluence of Arges and Doamnei Rivers) used for flood control, as well as the inner polder having an agricultural use, were considered – Figure 15.

After rune, the UNDA model provides:
- The kilometer position of the section
- The table with the geometrical and resistance characteristics
- The hydraulic works along the river
- The initial situation in the steady flow
- The table with results concerning the unsteady flow at every computing time in the particular sections
- The table with the maximum values (water levels and discharges) in all computing sections
- The table with the flood volumes for each section
- The list of the input discharge hydrographs
- The maximum error in estimating the differences of the water level in a specific point at a given moment.
- The modulus value of the error in assessing the differences of the water level.

The UNDA Model

This model simulates the routing of the floods along the natural or managed river courses. The UNDA model simulates the one-dimensional, unsteady flows with free surface that is able to simulate both the motion along the one-thread-shaped channels and ring - shaped or dendritical - shaped networks. It is based on the system of equations Saint Venant, numerically integrated in finite differentials on a rectangular grid in the plane X, T. To do that, an implicit scheme with the lining of the equations was used and for a certain time step the algorithm of double scanning has been considered.

$$\partial Z/\partial X+\alpha'/g*\partial V/\partial T+\alpha''/g*V*\partial V/\partial X+JE=0$$
$$\partial A/\partial T+\partial Q/\partial X=0$$

where:

$JE=V^2 / (C^2*RH)$ [Chézy]

$C=RH^{1/6}/n$ [Manning]

The program operates the regular cross sections of the riverbed as well as the following types of particular sections:

- injected tributary;
- confluence of long tributary
- transversal dam;
- lateral non-permanent storage (polder);
- water release work of a polder;
- cross sections at the hydrological stations;
- branch splited from a ring-shaped network;
- branch of a ring-shaped network at a confluence;
- discontinuity resulted from the arrangements of the networks as one-thread shape.

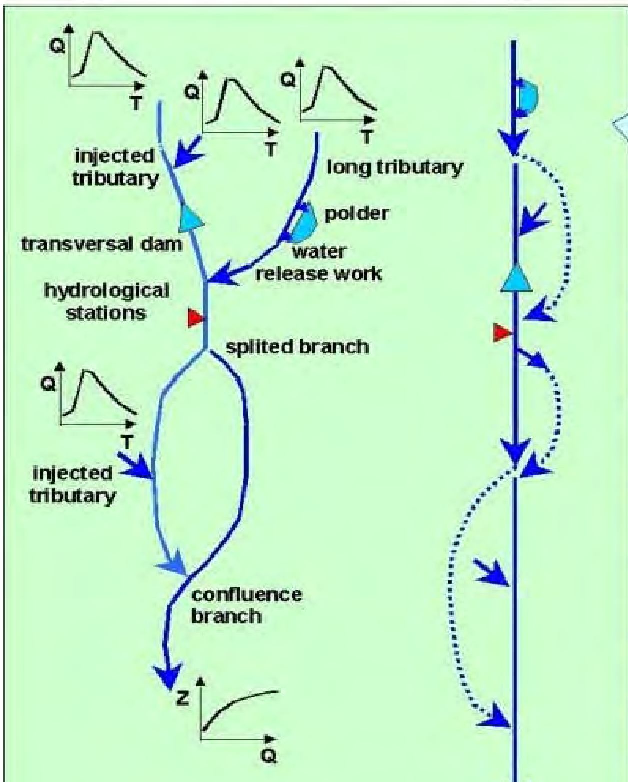
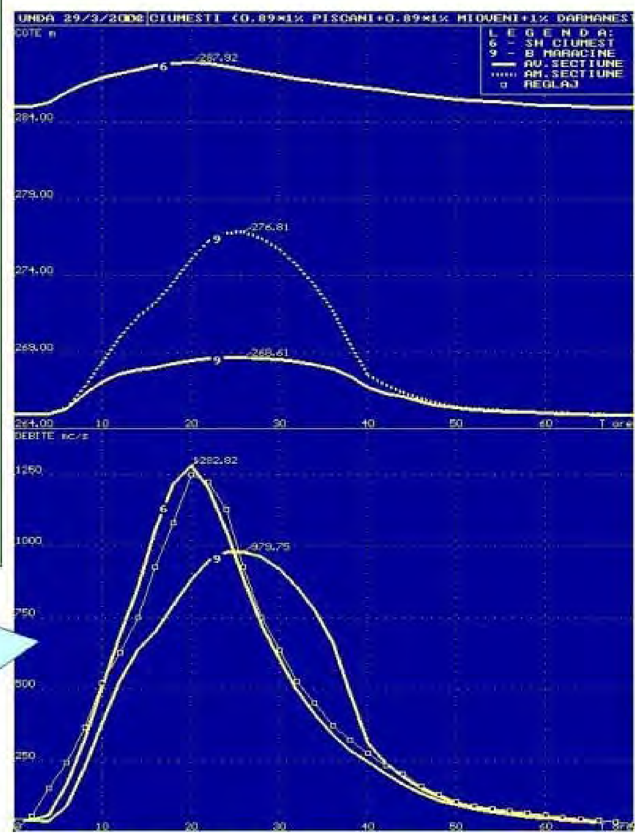


Figure 14



The results of the model are given in a txt file and graphically displayed on the computer monitor with the possibility to save it as bmp file.

The standard graphs are water level hydrographs associated with discharge hydrographs for one or many particular sections.

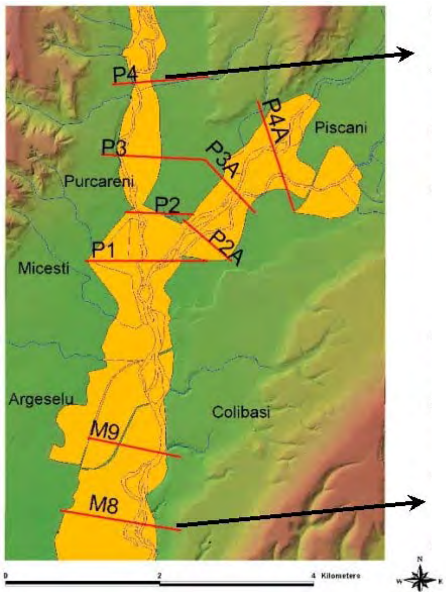
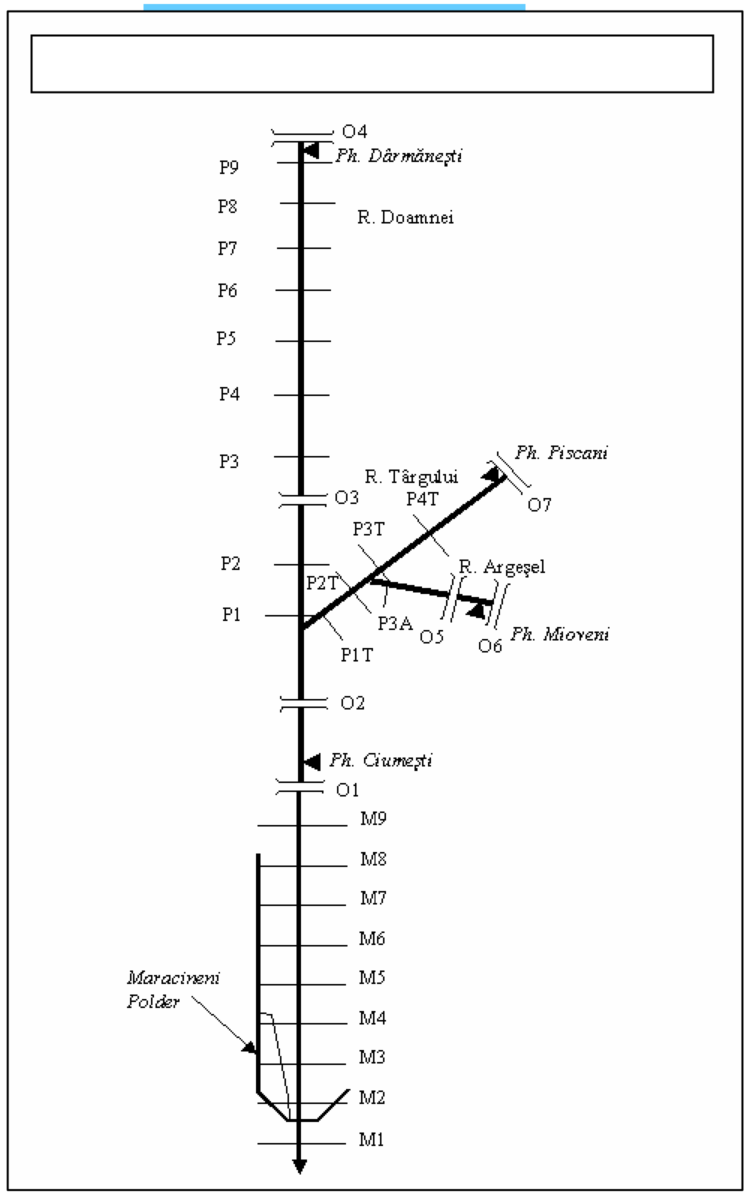


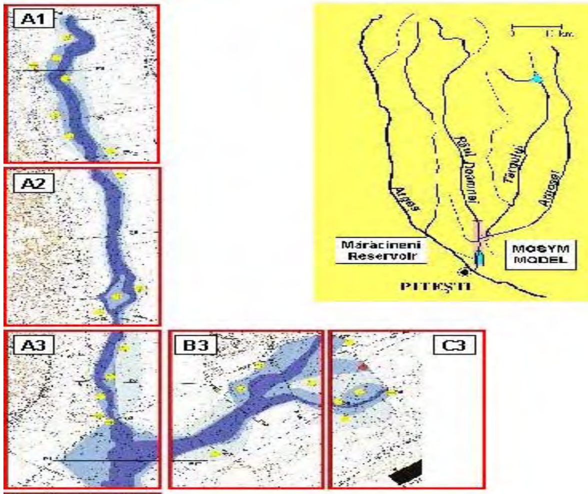
Figure 15

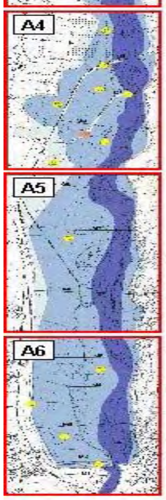


Taking into account the results provided by the model, the areas that are flooded for the peak discharges of 0.1%, 1%, and 10% probability of exceedance have been drawn as it is shown underneath.

In order to determine the maps of the flooding risk the following data have been used: topographic data, GIS maps, flood hazard map, water management of the river basin, data on the flood prone areas (socio -economic and environment objectives) and the technical regulations and standards concerning the accepted vulnerability.

In order to determine the vulnerability map the land cover/land use map determined by GIS application was used – Figures 16, 17.





In the frame of the MOSYM Project a flooding risk map has been achieved in the NIMH for a pilot area. The pilot river reach encompasses the Doamnei River upstream of the confluence with thr Arges River, comprising Doamnei River downstream Darmanesti Hydrological Station, Targului River downstream Piscani Station as well as the Argesel River downstream Mioveni. According to the NIMH methodology the hydrological hazard has been defined at the stations by the synthetic flood waves of several exceeding probabilities. The inundation strips have been assessed by use of UNDA Hydraulic Model. The vulnerability of the objectives subject to flooding expressed in terms of accepted exceeding probabilities has been established in compliance with the existing Romanian Standards. The cartographic method of the flooding risk map has been partially automated using the Coreldrw and GIS

Figure 16

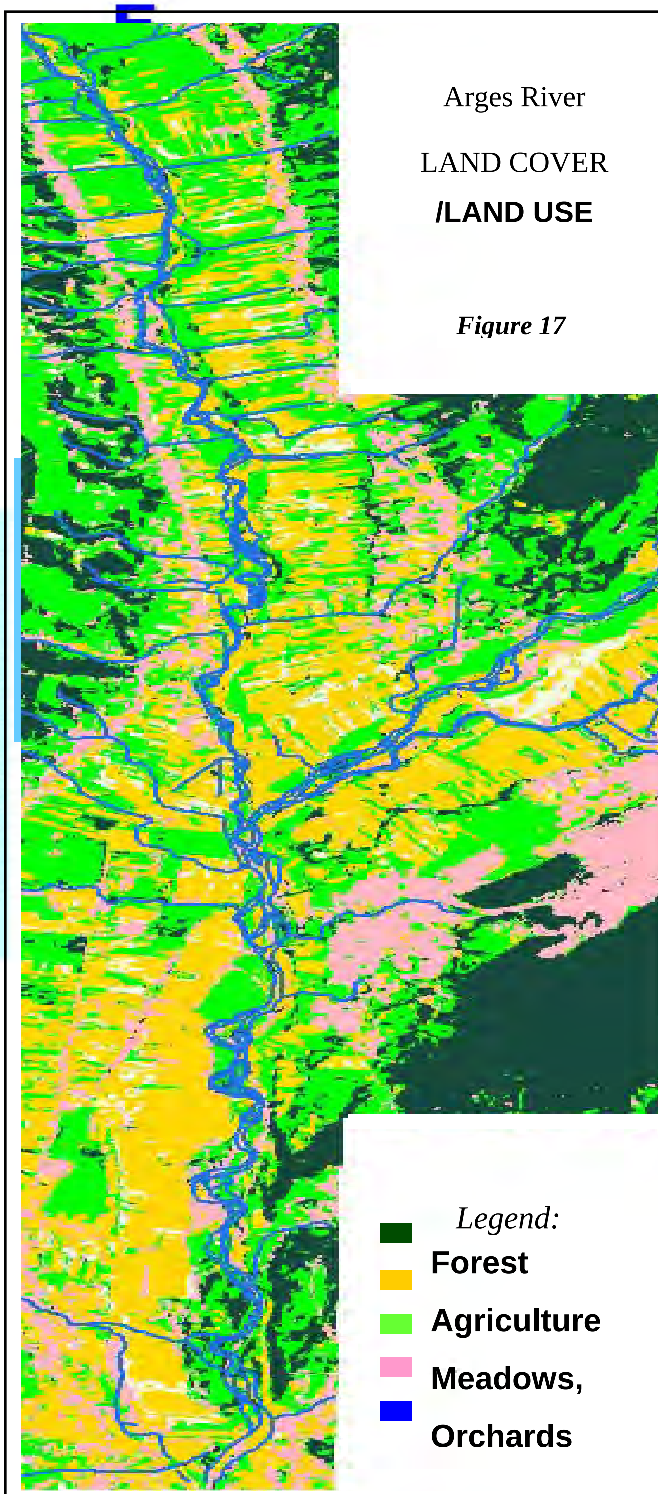


Figure 17

The flooding risk map is performed on the one hand, by identifying the parcels located in the contingency of the river bed that are able to be flooded with a given frequency and considering the “assumed” frequency of flooding, on the other hand.

If the accepted frequency (probability of exceedance) is smaller than the assumed frequency, the parcel is considered endangered and conversely.

In the figure presented on the right side it is shown the satellite map of the land-cover encompassing the five categories of uses. The following five categories of the land cover are deemed: the forest, agriculture terrain, meadow and orchard zones, urban areas as well as the riverbeds. For the assumed probabilities the following values have been considered: forest area - 20%, agriculture terrain - 10%, meadows and orchards - 20%, dwelling in rural areas - 5%, communication ways - 1% dams and levees - 0.1%.

The land uses located in the studied area in general satisfy the attribute of “protected” zone at inundation except two very critical zones concerning the communication ways which are located by circles marked in red color on the map bellow (Figure 18), namely:

- The intersection of the modernized way Mioveni-Piscani with the railway Pitesti-Campulung, the flooding originating from the flood pain of Argesel River, downstream the bridge 06.
- On the road linking Ciumesti and Mioveni, after the high passage over the railway towards the bridge O1.

These two points are of an outstanding economic importance having a significant impact both on the railway circulation to and from Pitesti City (capital of the Arges County) and the Dacia-Renault industry of cars. In the range of the transited floods the Maracineni non-permanent water storage achieves to satisfy its designed role. At the 1 % flood it performs a peak discharge mitigation of 25%, without jeopardizing the agriculture terrain from upstream of the water storage. The inner levee of the storage is not overflowed unless the probability of exceedance is less than 5%.

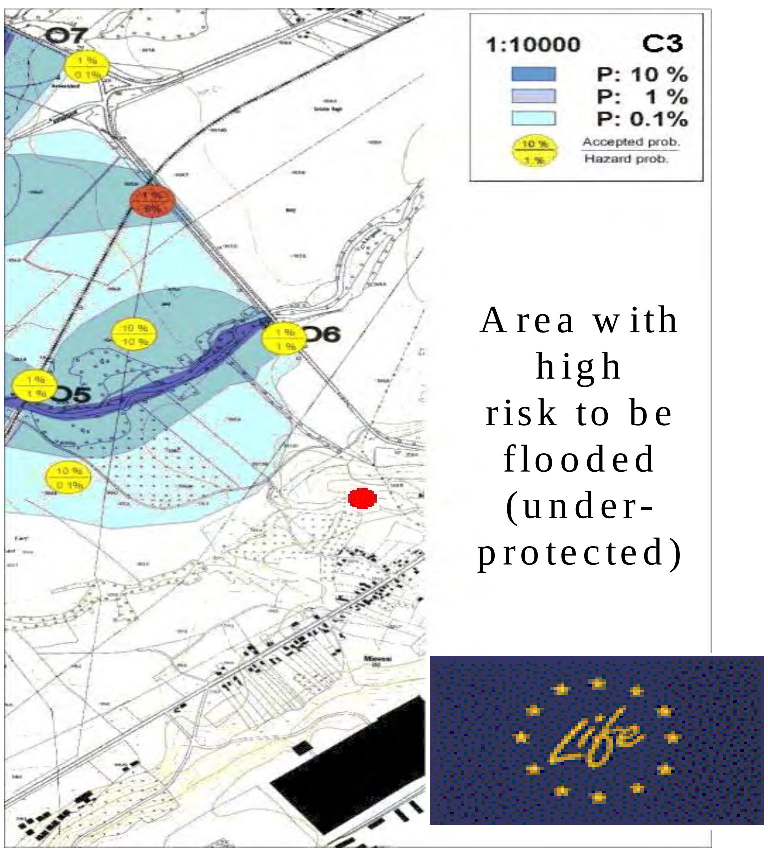


Figure 18

The presented methodology is applied in the EU area and is recommended in Romania, too.

III. Accidental pollution modeling

A. River Pollution Modeling

The Danube Water Quality Model (DWQM) is a part of the Danube pollution reduction Programme. The simulations of this model have been conducted to support the Trans-boundary Analysis as well as to support the definition of priority measures of the Pollution Reduction Programme.

A part of the model consists of the schematization of the river basin. The river network is divided into segments. In case of the Danube basin the following hypotheses have been made:

- Segments smaller than 10 Km were joined into larger units,
- Parallel stretches were joined to singular stretches with a comparable cross section and length.

The schematization of the catchment is very simple: the catchment is divided over the Danube countries.

The water balance model forms the necessary basis for the water quality model. The following quantities are to be computed for the segments, as a function of time:

- The inflows and outflows (m3/s),
- The water volume (m3),
- The streamflow velocity (m/s),
- The water depth (m).

On the basis of the presented model, the set up of the water balance is done in three steps:

- Mapping of the catchment of the Danube,
- The computation of the flows,
- The computation of the remaining segment characteristics.

The composition of the water balances is based on measured flow data for a number of specific stations. In between those stations the diffuse inflows are back-computed. In this procedure, the unknown diffuse inflows are assumed proportional to the increase of the catchment area along the river. For this purpose, a mapping of the catchment to the river network is made.

The mapping of the catchment is based on information about the total catchment area along the river. Based on this information an interpolation can be made to find the total catchment and the division over the countries for all river network segments. The interpolation has to be made proportional to the length of the river segments. For a number of locations the river flows are measured and for the segments between two measured locations, the flows are interpolated (the interpolation is made proportional to the catchment area, which was computed earlier). The diffuse inflows per river segment are computed from the steady state water balance equation per segment. The computation of the remaining segment characteristics is based on:

- the steady-state river flow patterns which are computed for every hydrological period,
- river cross section data,
- river slope data.

As starting point the following data can be used:
- table of water level, wet cross section and river width,
- table of river flow, wet cross section and river width,
- table of river flow, streamflow velocity and river width.

For every hydrological period and for every computational segment, the following procedure is followed:
- the steady state flow Q is used to compute the velocity v and depth H,
- the wet cross section A is computed,
- the segment volume is computed by multiplying the cross section A and the segment length L.

The final step is a correction of the river flows Q, to account for the variation of the wet cross-section A. This is done to satisfy the water balance equation for all segments. The pollution sources can be introduced in the model in four ways:
- As a point emission,
- As a distributed emission causing a constant load in the river,
- As a distributed emission causing a constant concentration in the river,
- As a distributed emission causing a concentration proportional to the river flow.

If point sources are located on or very close to those rivers stretch which are explicitly included in the model, they are introduced in the model as a point emission at the correct location in the network. The remaining point sources are treated as a distributed emission causing a constant load in the river.

Diffuse sources are always introduced in the model as a distributed emission, of one of the three types mentioned above.

The concentration in the river as result of the tree types of distributed sources mentioned above and classified is shown in the table 1.

Table 1. Sources classification

Point sources	***Classification***
Discharges from sewer system (treated and untreated)	*Point source, or distributed with constant load*
Discharges of industry (treated and untreated)	*Point source, or distributed with constant load*
Effluents from manure treatment plants	*Point source, or distributed with constant load*
Diffuse sources	***Classification***
Direct discharges of private household	*Distributed with constant load*

Storm water overflow	*Distributed with constant load*
Direct discharge of manure	*Distributed with constant load*
Base flow	*Distributed with constant concentration*
Erosion, runoff (from agriculture land)	*Distributed with concentration proportional to flow*
Erosion, runoff from forests and others	*Distributed with concentration proportional to flow*

The **Danube Basin Alarm Model (DBAM)** is an operational model for the simulation of the transport and decay of substances that have been released during accidental spills. The model forms an integral part of the Danube Accident Emergency Warning System (AEWS) in operation in the Danube River Basin, and supports the assessment of the consequences of accidental spills for the river water users.

The DBAM model – system is used by the Principal International Alert Centers (PIACs) of the Danube AEWS as a tool to evaluate the possible impacts of a trans-boundary water pollution incident. First of all the DBAM is aimed to assess the expected concentration of a pollution plume and its time of arrival at a particular river section downstream.
The model uses flow times from the point of accident to the point of observation. Furthermore the model uses dispersion information longitudinally and cross – section. The flow time model is based on tabular relationships.
The river is subdivided into reaches with approximately constant flow along the reach. The reaches are subdivided into segments with approximately constant velocity.

To generate a velocity-flow table there are two possibilities:

- A gauging station is available with a Q-h relationship and information on the cross section (A-h) relationship. A v-Q relationship can be derived from that,
- No gauging station is available – from the shape of the cross – section (A-h) and the slope of the bed (or more precisely the energy grade line together with a roughness factor in Manning or Chezy, the v – Q relationship can be derived from Mannings equation (assuming stationary flow for sufficient long time).

This model is used for the Danube river basin but it can be extended for the main tributaries: Tisza, Somes, Mures, Cris, Siret, Prut, Olt, Arges, Jiu and Ialomita Figure 19.

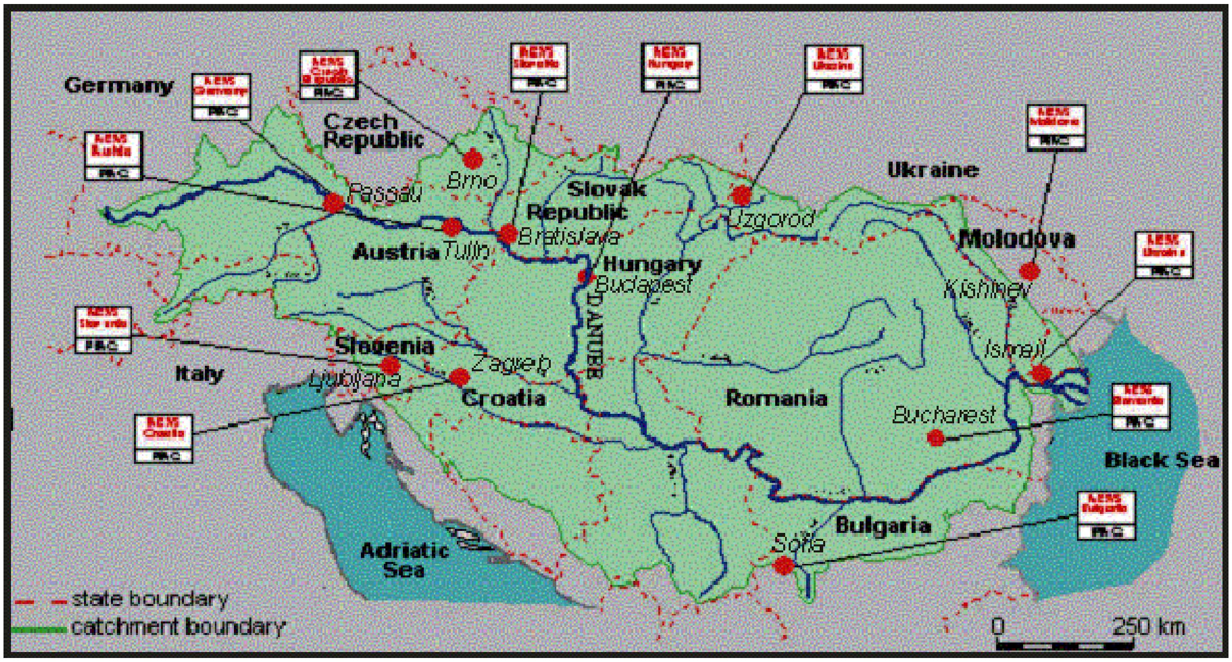


Figure 19. Area of Model application Danube Water Quality Model (DWQM)

The Danube Basin Alarm Model (DBAM) aims at *predicting the travel time of the concentration* in a cloud of pollutants released in the river system as the result of an accidental spill. The focus is on large scale events of a trans-boundary nature. The model is intended to be used for a first and rapid assessment under operational conditions. The model is intended to b used for a first and rapid assessment under operational conditions: the run-time should be short and the necessary input data should be limited.

The model solves the 1D advection diffusion equation analytically, using the flow time from the point of spill to the point of observation.
The longitudinal dispersion will be composed from the weighted average of the dispersion in all segments.

The thus derived 1D solution can be considered to be the integral of the 2D solution in the transversal direction. To compute the 2-D solution is then a question of estimating the distribution of a known 1D mass over the cross-section. A transversally 1D diffusion equation solution can be used for that, taking into account the flow-time and the transversal diffusion coefficient.

The "dead zone model" is commonly accepted as a basis for spills models in river systems: the same mathematical model is used in the Rhine basin, Elbe basin and for several rivers in France. The hypothesis of the model fit to a uniform river stretch with constant flow characteristics. For the practical application to the Danube River and its main tributaries, the solution has been expanded for confluences and bifurcations, taking into account the spatial variability of the hydraulic characteristics of the river system.

Actual calculation procedure consists of two steps:
1. The calculation of the hydraulic coefficients (discharge Q(x) and velocity U(x)).
2. The calculation of the concentration C(x,t).

The hydraulic coefficients Q and U are calculated on the basis of actual hydrological input data: observed values of either the water level or the discharge at selected hydrological stations at the time of the accident. The DBAM uses tabulated relations between the water level and the discharge ("rating curves") to calculate the actual discharge. In a similar way, tabulated relations between the discharge/water level and the velocity are used to calculate the actual velocity.

As soon as the local flow is known, velocities can be derived from tables relating flows and velocity. These tables will have to be made either on the basis of measurements (at location where a Q-h curve together with a A-h curve are known), either on the basis of a simplified analytical model according to Manning-Strickler, or on the basis of the numerical hydrodynamic model for the river stretch.

The concentrations are computed on the basis of actual spill input data: the location of the spill and the amount of material spilled.

Table 2. Essential steps in the calculation method of DBAM

Phase in the calculation procedure	***Potential inaccuracies***
1) Collection of hydrology input data during the event	Inaccuracy or even unavailability of long term meteorological forecast and hydrology forecast
2) Computation of discharges from water levels, or vice versa, by using rating curves	Inaccuracy of the rating curves in DBAM
3) Computation of river stream flow velocity, by using built-in tables and the actual water level or river discharge	Inaccuracy of the velocity tables in DBAM
4) Computation of the propagation of the cloud of pollutants (travel time, concentration level)	Inaccuracy of the calibrated model coefficients b (affecting travel time and concentration) and a (affecting only concentrations)
Overall concept of DBAM	Inaccuracy of the underlying assumptions, in particular: • 1-dimensional modeling approach (no variations over the cross-section); • quasi steady hydrology.

The DBAM software consists of three main parts:
- Part 1, consisting of a user interface program, reading schematization data and enabling the user to perform selections and provide input on calamitous spills, needed for the model simulations. This part generates the case-dependent input files for the model simulation.

➢ Part 2, consisting of the model simulation programme. It reads the static, or in other word, system input data defining the Danube River and it reads the case-dependent input files, defining the spill and associated hydrology. The simulation programme produces output files containing the model simulation results at selected locations at selected times.

➢ Part 3, consisting of the model result display program. It reads the model simulation result files together with river schematization data and it produces graphics on screen and tables in print.

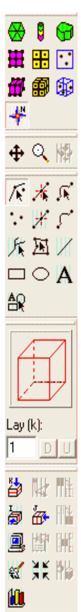
The three main parts are separately executable. They are invoked from a common user interface that hides all those aspects not strictly related to the calamity at hand.
The accuracy of the DBAM depends on more than just an accurate calibration of the model parameters.

Tracer experiments were carried out for few river stretches. One of them was performed in 1994 along the Dambovita, a tributary of the Arges River. The dispersion coefficient has been determined by using Rhodamine.

Both applications could be alternative applications for accidental pollution modeling which should be included under the DSS interface.

B. Groundwater Pollution Modeling System (GMS)

GMS is one of the most widely used tools for groundwater flow and transport simulations. Sophisticated and comprehensive, this environment is maybe the first choice for such modeling software. It provides tools (Figure 20) for every phase of a groundwater simulation, supporting both finite-difference and finite-element models in 2D and 3D.



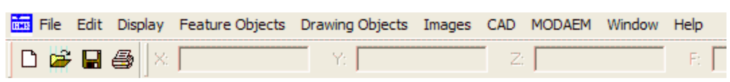


Figure 20. GMS menu

As Windows software, GMS uses the functionality and versatility of this operating system. Both, preprocessing and post processing, is done through a graphical environment, building the models and viewing the results being very easy and intuitive. Enharitage of GIS concepts make building of modeling domains an easy task.

Models can be built using digital maps and elevation models for reference and source data. Post processing the results can also be made with ease for both steady-state and transient simulations.
As finite difference models for the flow, GMS integrates a well known software, Modflow, and for the transport MT3D.

MODFLOW is a 3D, cell-centered (Figure 21 and 22), finite difference, saturated flow model developed by the United States Geological Survey (McDonald & Harbaugh, 1988). It can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It has a modular structure that allows it to be easily modified to adapt the code for a particular application.

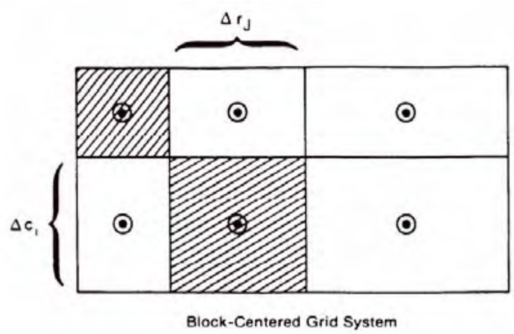


Figure 21. Block centered grid

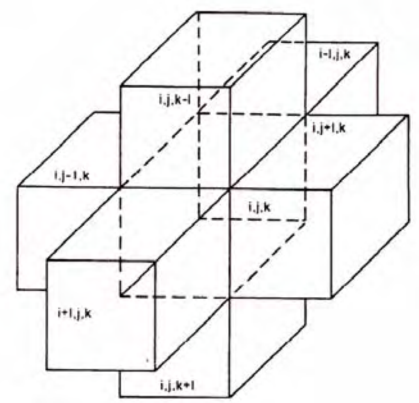


Figure 22. Spatial cells indexes

With GMS, a special version of Modflow is distributed. Modflow-2000 is the third major release of the USGS 3D finite difference groundwater model, as older versions being Modflow 96, 88 and 83. Written in Fortran 77 with Fortran 90 extensions, it simulates steady and nonsteady flow in an irregularly shaped system. Aquifer layers can be confined, unconfined, or a combination of confined and unconfined. Flow from external stresses, such as flow to wells, area recharge, evapotranspiration, flow to drains, and flow through river beds, can be simulated. Hydraulic conductivities or transmissivities for any layer may differ spatially and be anisotropic and the storage coefficient may be heterogeneous. With a block succession structure, the computer code can be used to simulate a great variety of situations, useful both in real situations and in learning process.

The groundwater flow equation is solved using the finite difference approximation. The flow region is subdivided into blocks in which the medium properties are assumed to be uniform. In plan view the blocks are made from a grid of mutually perpendicular lines that may be variably spaced. Model layers can have varying thickness. A flow equation is written for each block, called a cell. The flow equation is:

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_s\frac{\partial h}{\partial t}$$

(1)

where: K_{xx}, K_{yy} and K_{zz} are hydraulic conductivities along the x, y, z coordinates assumed to be parallel to the major axes of hydraulic conductivity, h is the head, W is the source-sink term and S_s the specific storage of the porous material. The equation is derived from a continuity equation in which the flow is expressed through Darcy's relation. The boundary conditions can be heads (Dirichlet conditions), fluxes (Newmann conditions) or mixed (Cauchy conditions).

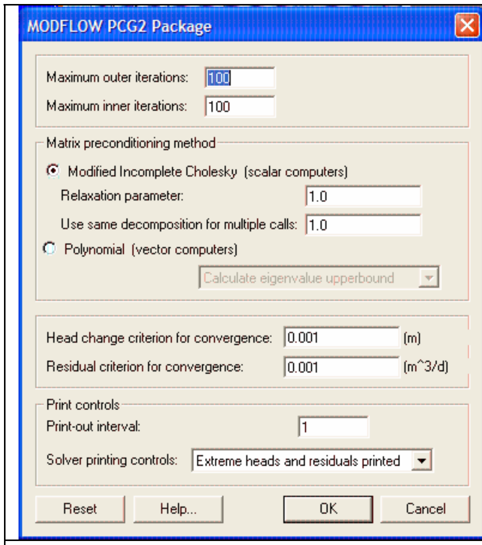


Figure 23. MODFLOW package

Several solvers (Figure 23) are provided for solving the resulting matrix problem; the user can choose the best solver for the particular problem. Flow rate and cumulative volume balances from each type of inflow and outflow are computed for each time step.
Results can be presented as isolines of hydraulic head, outlined or filled. Water balance can be computed.
Well documented, years of experience and tested with many benchmark problems it has proved his functionality.

The modular 3-D transport model referred to as **MT3D** was originally developed by Chunmiao Zheng (1990). In the past several years, various versions of the MT3D code have been commonly used in contaminant transport modeling and remediation assessment studies. The MS stands for Multi-Species. It includes three major classes of transport solution techniques: the standard finite-difference method, the particle-tracking-based Eulerian-Lagrangian methods and the higher-order finite-volume TVD method.

MT3DMS is developed for use with any block-centered finite-difference flow model such as MODFLOW and it is based on the assumption that changes in the concentration field will not affect the flow field significantly.

It simulates several processes as advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW. MT3DMS is used in conjunction with MODFLOW in a two step flow and transport simulation. Heads and cell-by-cell flux terms are computed by MODFLOW during the flow simulation and are written to a specially formatted file. This file is then read by MT3DMS and utilized as the flow field for the transport portion of the simulation.

The equation solved is:

$$\frac{\partial\left(\theta C^k\right)}{\partial t}=\frac{\partial}{\partial x_i}\left(\theta D_{ij}\frac{\partial C^k}{\partial x_j}\right)-\frac{\partial}{\partial x_i}\left(\theta v_i C^k\right)+q_s C_s^k+\sum R_n \qquad (2)$$

where: θ is the porosity, C^k the dissolved concentration of species k, D_{ij} the hydrodynamic dispersion coefficient tensor, v_i seepage or linear pore water velocity, related with Darcy flux through the relationship, $v_i = {}^{q_i}\!/_{\theta}$, q_s volumetric flow rate per unit volume of aquifer representing fluid sources (positive) and sinks (negative), C_s^k the concentration of the source or sink flux for species k and $\sum R_n$ the chemical reaction term.

Each phenomenon is called through a package (Figure 24), GMS providing an easy way to choose. With transport models not dominated by advection, the standard finite method can be used to solve de dispersive term of the equation. When the advection term is strongly influencing the phenomenon, TVD (total-variation-diminishing) schemes are used for such terms. As an alternative the MOC or MMOC algorithms (particle-tracking techniques) can be used. But obviously, with the risk of numerical instabilities, for both dispersion and advection, finite difference method can be used.

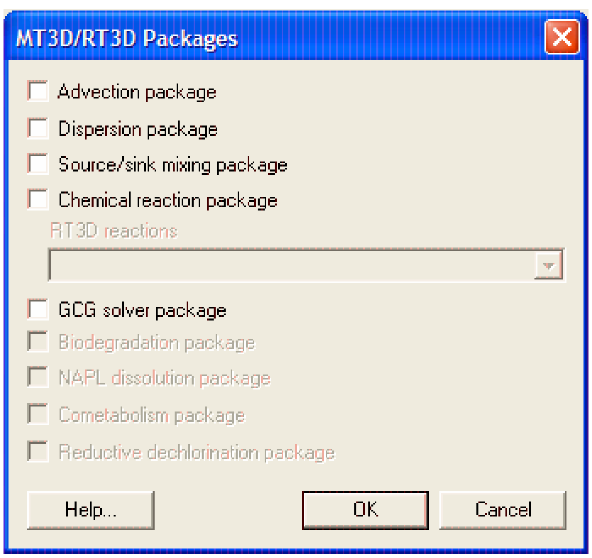


Figure 24. MT3D package options.

The MT3DMS code is capable of handling equilibrium-controlled linear or nonlinear sorption, non-equilibrium (rate-limited) sorption, and first-order reaction that can represent radioactive decay or provide an approximate representation of biodegradation.

MT3D calls an iterative solver based on generalized conjugate gradient methods to remove stability constraints on the transport time step size.

As discretization MT3DMS uses the same structure as Modflow (Figure 25).

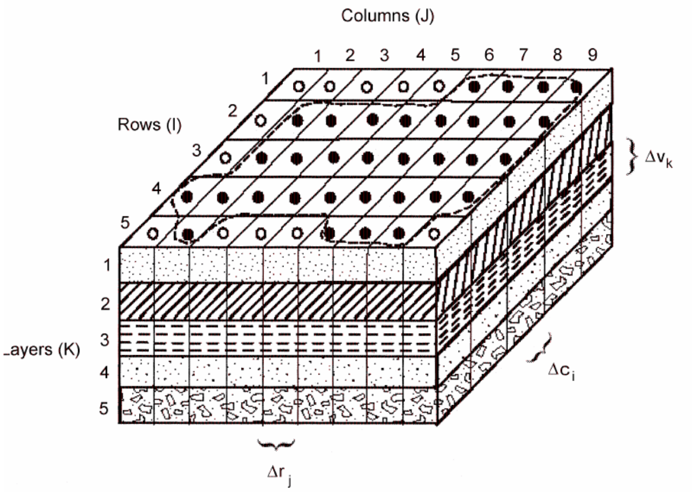


Figure 25. Spatial discretization scheme for MT3D

The tricky part is the time discretization for non steady simulations. The simulation time is divided into stress periods (i.e. periods with the same boundary conditions) for which the flow equation is solved, each stress period being divided into its own time steps (Figure 26). For each time step in flow equation, time steps for transport equation are defined and the equation solved.

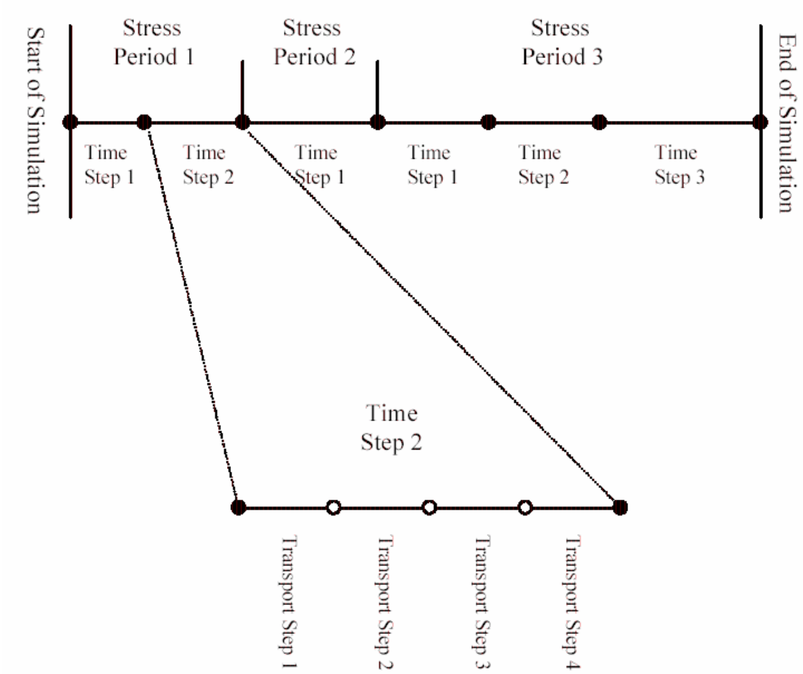


Figure 26. Temporal discretization scheme for MT3D

Results are presented in GMS4 as isolines of equal concentration, the possibility of animation being provided.

Concluding, GMS4 through Modflow and MT3DMS is powerful tool, useful in various situations, easy to use, but with the necessity of a well understanding for the mathematics and the physics behind.

A large application in Crisuri Basin was provided in a NATO contract, during 2001-2003. UTCB and INHGA researchers have good abilities in using this application; it would be a good alternative to include this model for groundwater management.

IV. Optimization Models in Romanian Applications

Large scale reservoir systems serve many important purposes, including water supply, flood control, hydropower production, low flow augmentation for water quality enhancement, environmental and recreational objectives etc. Optimization of operations for multipurpose reservoir is difficult due to this mix of quantitative and qualitative uses. The problem has become more important in the recent years with the increased emphasis on environmental and population welfare aspects, while some of these objectives may be non-commensurated into monetary units, and conflicting in nature.
However, optimal tradeoff relationships must be developed in order to satisfy the various purposes as closely as possible in accordance with the perceptions of both decision maker (the reservoir system operator) and representatives of decision – influence groups.

The hydro-technical works on the rivers in Romania are characterized by the existence of a reservoir of big size (between 300 - 1000 mil. sqm utile volume), located on the up-streams of a river, followed on in down-stream by a cascade of small lakes/ reservoirs (between 2 - 100 mil. sqm utile volume). In very few cases there appear two or more big lakes realized on the same important basin and having the hydro-graphic network inter-connected.

For the head of cascade big reservoir, which allows for the long-term regularizing of the affluent stocks, the traditional approach for its optimal operating decomposes the initial problem in two, much simpler, sub-problems:
1. One sub-problem of long-term optimization (for strategic operating), formulated in probabilistic or fuzzy context, with monthly time pace. Such and optimizing model is further described and exemplified in paragraph (i).
2. A sub-problem of, short term, tactical operating, formulated in deterministic conditions, with regard to the data/ elements of stocking nature (affluent debits, requests for energy, etc). However, the solution of this sub-problem should lead to its inclusion in/ compliance with the policy of strategic operating of the big accumulation.

For the cascade of small reservoirs from down-stream it arises the issue of optimizing the exploitation on long-term (daily horizon), with hourly or multi-hourly time paces. It is formulated in deterministic context, assuming that there are known: the policy of tactical operation of the head of cascade lake, affluent debits from the differences of basins, debits taken-out for the users, the status of availability of the hydro-power stations, etc.

In conclusion, most of the optimization procedures refer to the reservoirs volumes optimization for multipurpose objectives or in case of flood / low flow management.

The problem needs to be adequately formulated, depending of the described scenarios:
1. Bi-dimensional optimization problem for water management in a cascade of reservoirs: long term strategic optimization/short term tactical operational optimization

2. Multi-objective large reservoirs water management
a. Fuzzy rule-based model for long term reservoir operation
b. Statistical water management system optimized functional parameters – SIMOPT REG Model

3. Reservoir optimal policy for flood management
a. One reservoir with a certain class number for outflow devices
b. Couple of reservoir-polder system

A. Water Management System (WMS) optimization for water allocation in the network

(i) SIMOPT Model that aims to the analysis of long-term WMS operation and have as the main results the statistical WMS functional parameters (Violeta Visan, 1998); these model originate in 1990 (Violeta Visan) but there are a lot further developed and improved. SIMOPT simulation-optimization model is based on an improved version of the Ford' and Fulkerson' out-of-kilter algorithm as optimization technique.

A real WMS might be modeled by an arcs-nodes network so the real WMS operation problem becomes a problem of flows in networks. The nodes and oriented arcs as well as their characteristics such as lower and upper limits and associated costs will be the direct analog of the physical and operational WMS characteristics.
- Arcs represent both physical and conventional elements of WMS such as river branches, channels or pipes, water user demands or other water management requirements, trenches of water reservoirs volumes, water levels in channels or rivers, and so on.
- Nodes are junctions of at least two arcs and stand for locations of lakes or water reservoirs; confluences of river branches, water withdrawal or wastewater discharge points, etc.
- Quantitative features of water resources, water users and water reservoirs or other water works are expressed as constraints of non-violating the lower and upper limits assigned on arcs.
- Options of WMS functioning i.e. water retention/discharge in/from the reservoirs or diversion of water from one part of WMS to the other in order to meet water demands

as well as the water user economic benefit or loss related to the degree of water demand, are the defining elements of the objective function and are conventionally expressed by the means of costs attached to the arcs.

- A closed network is needed to comply with the flow continuity requirement. This is achieved by adding a supplementary node *r* with no physical meaning named “balance node”; all arcs whose origins or destinations have no physical correspondence join to this node.

The problem of optimizing the WMS operation is formulated like a flow in networks problem as following: to find the flow that minimize the cost in the whole network while meeting the constraints of continuity in nodes and the constraints of non-exceeding lower and upper flow limits on arcs.

Conversion of WMS in the arcs-nodes network and the adequate choice of costs and limits on arcs are steps of a unitary process and depend on the goal of the respective model.

The main statistical parameters used as indicators of long-term WMS operation are the following:

- long-term reservoir operation rules;
- actual degree of meeting water demand expressed in terms of year, month and quantity percentage;
- other indicators of WMS behavior during drought periods such as: maximum, average and minimum values of actual water distributed to different users and number of months in which each of these values appears;
- time variation of reservoir volumes and levels, number of months when reservoirs are empty and full respectively, yearly and monthly average level, and so on;
- indicators of hydropower plants performance: time variation of monthly available power, monthly, seasonal and yearly average energy production, yearly number of HPP operation hours;
- pumping energy consumption for irrigation;
- river flow hydrograph in different control points as resulting from calculations performed.

SIMOPTEXP Model realizes an optimal water distribution within the all WMS both on long-term and on short-term that minimizes the economic losses of not meeting water demands.

Long-term optimization is achieved by using appropriate pre-established reservoir operation rules of dispatcher chart type that imply the reservoir volume zoning.

Short-term optimization is attained during each analysis time interval and consists in a convenient distribution of water between reservoirs and water users which minimizes the costs associated both to not meeting water demands and to not observing the optimal reservoir operation rules.

Balancing the goal of retaining water in reservoirs with that of discharging water for meeting water demands is needed in order to solve the short-term operation problem and is realized by fixing a proper system of costs attached to the corresponding arcs.

Model achieves the following functions:

- Simulation of WMS operation on monthly (or ten days) intervals and on a year series;
- Optimization of WMS operation in each time interval from the year series by the means of "out-of-kilter" algorithm.

The convenient processing of results obtained in each time interval of the year series analyzed gives the opportunity to calculate parameters of WMS that characterize its functioning.

The economic concept of water use is the starting point of ***water demands modeling***. According to this concept, a "utility/benefit function" or a "loss function" might be associated to each water user that represents the benefits obtained by using water or the damages produced due to the water shortage.

This way, depending on the specific character of each water user, its water demand might be considered as a single value, in which case the loss function has a single slope, or consisting in F trenches when the loss function is represented by F line segments of different slopes.

A unitary cost C_f which expresses the unitary economic loss produced when the user missed one unit of necessary flow is attached to the single water demand or to each water demand trench f.

Weight or priority coefficients might be used instead of the real unitary costs when the "utility/benefit function" or the "loss function" is not available. The weight/priority coefficient values are conventionally established in such a way as to reflect the relative importance of meeting different water demands or water demand trenches within the whole WMS.

Weight coefficient attached to a water demand or water demand trench should be as higher in absolute value as that water demand or water demand trench is more important from the prospective of water shortage consequences. Thus it is possible to catch into the analysis a more refined way of meeting water demands for some important water users which, for instance, have the possibility to recycle water:

- allot water during drought periods only for the trench corresponding to the minimum necessary need;
- cover the rest of water trenches too in periods with enough water, and so reduce the user operation costs.

Domestic and industrial water supply: representation of this kind of users in the arcs-nodes network corresponds to the above mentioned principles; lower limits on arcs are zero and higher limits have values with monthly variation that follow the same pattern in each year of the time series.

Irrigation: the dispatch charts established and used for reservoir operation in Romania contain one curve corresponding to irrigation water demand which is calculated based on the so called “80% irrigation norm” and should be met integrally in all years. Consequently, irrigation water demand is represented in the arcs-nodes network by two arcs oriented from the in-taken node to the node *r*; lower limit values on these arcs are zero but upper limits values having a continuous variation from month to month and from year to year correspond to the 80% demand and respectively to the difference between total demand and 80% demand.

Water demand for hydro-energy production: the best operation of the hydro-power plants (HPP) means to obtain the optimal yearly hydro-energy production while observing its required distribution along the year. Energy relation $E = kQH\eta$ is a non-linear function whose optimum can not be directly achieved through the out-of-kilter algorithm which is a linear programming technique. The following procedures might be applied to elude the problem of direct optimization:
a) In case of reservoir where energy production prevails, the reservoir discharge hydrograph which was previously calculated to optimize the energy production becomes input for SIMPOT model;
b) When the energy production objective is subordinated to the needs of consuming water users, its optimization is no longer needed; the energy production as indicator of WMS performance is calculated from the results of the whole analysis.
c) In case of water reservoirs with so called” complex users”, assuming H and η are approximately constant, the water demand for energy production expressed by the reservoir discharge in month t and written Q^t_{nec}, is calculated with relation ($Q^t_{nec} = Q_i * T^t / 730$) where Q_i is the HPP installed flow and T^t is the number of functioning hours in month t which is previously established according to HPP place in the power load chart.

Long term reservoir operation rules of dispatcher chart type imply zoning of reservoir volume in trenches whose volumes may have constant or monthly variously values: $V^t_{total} = \sum_{i=1}^{T} Z^t_i$ t = 1– 12.

For exemplification purposes, Figure 27 where the reservoir volume is divided in six zones *(T=6)* corresponding to the dead volume (zone Z_1), volume reserved for water users (zones $Z_2 – Z_5$) and flood control volume (zone Z_6) are shown. Operation curves L_2, L_3 and L_4 are designed on the basis of expert judgment, multi-objective analysis or detailed long-term operation analysis.

Each volume zone Z_i corresponds to one category of water demand/water demand trench this having the meaning that in order to meet these demand water is discharged only from zone Z_i or higher zones Z_k $(i<k<=T)$ but never from lower zones Z_k $(k<i)$ which are kept for more important water demands. This correspondence is achieved by setting appropriate values to the weight coefficients attached to volume zones; these values

should be lower in absolute value than the weight coefficients attached to water demand/water demand trenches of the correspondent category.

In the arcs-nodes network, each reservoir is represented by one node j, one inflow arc oriented to j, one initial volume (r,j), T volume zone arcs all oriented from node j to node r and one discharge arc from node j (figure 28).

Continuity relation in node j is the volume balance relation in reservoir for each time interval t and the weight coefficients C_i attached to the volume zone arcs Z_i observe limiting condition.

Constraints of flow continuity in nodes and of non-violating lower and upper flow limits on arcs are respected under condition that these limits are properly established. For instance, as long as on the arcs representing the natural inflow and the initial volume in reservoirs, actual flow x_{ij} in each time interval is just the natural inflow and the initial volume respectively, the lower limit equals the upper limit.

The objective function in each time interval is the minimization of costs due on one hand to not meeting water demands (actual water withdrawn by water users is lower than the nominated demand) and on the other hand due to lowering the reservoir levels under the optimal corresponding lines. The positive costs associated to not meeting the nominated water demands and to not preserving the optimum reservoir volumes, are replaced by negative costs associated to actual water withdrawn by users and to actual volumes achieved in reservoirs.

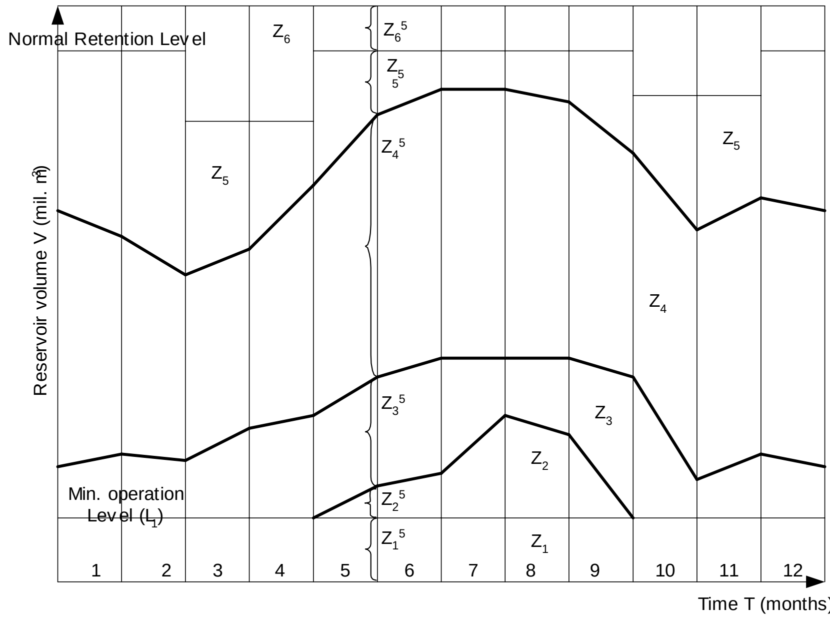


Figure 27. Division of reservoir capacity in volume zones

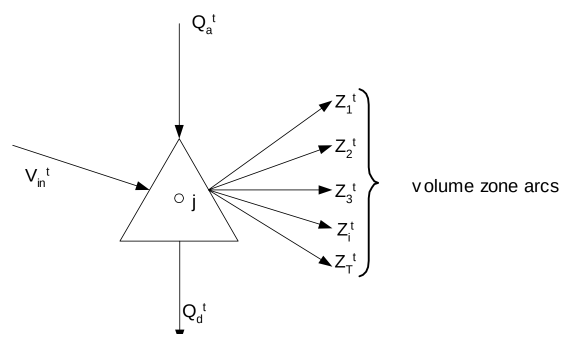


Figure 28. Water reservoir representation in the arcs-nodes network

General rules for setting up the weight coefficients according to WMS operation options are:

- Weight coefficient attached to a water demand or water demand trench should be as higher in absolute value as that water demand or water demand trench is more important from the prospective of water shortage consequences;
- Weight coefficient attached to a volume zone is lower in absolute value than the one attached to water demands supplied from that zone;
- Weight coefficient attached to a volume zone is should be as higher in absolute value comparing to weight coefficients attached to the other volume zones, as that zone is later in the process of discharging water for meeting water demands.

Apart from the general rules, there should be some ways to set up the system of weight coefficients, in order to comply with different *options specific* to each WMS as regards water reservoir or water diversion operation and meeting water demands; the analyst may wish for instance:

- some reservoirs to serve only some users;
- all or some reservoirs should be emptied totally or partially in a specific order;
- some supplementary flows to be discharged for energy production;
- spills to be limited;
- etc.

In setting up the system of weight coefficients it is important to identify different routes between two nodes in the arcs-nodes network on which the water transport is physically possible. In different words, setting up the weight coefficients on different arcs should be done in such a way that the resulting weight coefficient of different possible route would ensure the water to be transported according with the imposed or desired options.

SIMOPTEXP Model is especially useful within ramified or dendritic river basins for large multireservoir-multipurpose WMSs.

The runs of the attached computer programs should be preceded by the following:

- WMS transformation into the arcs-nodes network accordingly to model requirements as presented in the previous sub-chapters;
- Preparation of input data, among which those with continuous variation (from month to month and from one year to another) such as water inflows and irrigation water demands require a specific processing.

SIMOPT Model has been used mostly for analysis of WMS in the interconnected hydrographic space of Arges, Dambovita and Ialomita rivers (ARDI Project). This application will be developed further in demonstrating the performances of WATMAN package of models.

SIMOPTREG Model establishes the long term reservoir operation rules. Model target the establishment of reservoir operation rules type "dispatcher chart" similar to the ones used in SIMOPTEXP model. Transformation of the real WMS in an arcs-nodes network is also similar but the volume zones values for monthly time intervals are not known and should result by applying the model. The iterative computing procedure for each volume zone Z^t_i begins for $i=1$ and consists of the following stages*:*

a) Simulation of WMS operation on monthly intervals from a period of *interest (some years)* under the following assumptions:

- volume zone j which is calculated in the current iteration is limited to the reservoir storage capacity;
- volume zones calculated in the previous iterations have a known value Z^t_i $(i<=0<j)$;
- volume zones which should be calculated in the next iterations have zero values.

b) Optimization of WMS operation based on out-of-kilter algorithm in each month in the considered interval. Water discharges from reservoirs would only be made for water demands within importance category corresponding to volume zones $i <= j$. Reservoir inflow Q^σ_a plus volume existing in reservoir at the beginning of time interval should

cover volume needed to exist in volume zones $i < j$ at the end of time interval and discharge for meeting water demands. Reservoir function is described by the water (volume) balance on the zone arc j in the considered time interval.
Volume variation on the zone arc j in time interval is defined under the condition of a reservoir emptying and filling functions.
c) Calculation of cumulated monthly emptying is done the basis of emptying value series resulted in the previous stage going from the last time interval to the first one.
d) Calculation of monthly maximum values
e) Calculation of the existing volumes for each use in each dedicated area of the reservoir volumes
f) Calculation of storage volume available for next

The computer program for this model was developed in FORTARN language. Its version for personal computers is no longer available.

(ii) ALOC Model aims to be used by the dispatcher unit for planning of the monthly and three-monthly reservoir operation rules. It has to fulfill the following requirements:

- it should be a general model i.e. to fit to any WMS regardless its shape or reservoir and water user number;
- the corresponding computing program should be easily accessed by the user.

The integer linear programming technique based on Out-of-Kilter algorithm has been chosen again to comply with the generality requirement. That is why the most of the elements used in SIMOPT models for WMS describing are present in ALOC model as well but the arcs-nodes network is somehow different:

- first of all, the network is constructed on the whole prior to any use of the program which means that no arc and no node is added by the program itself;
- the water demand for each system is represented by one arc.

The model application gives the he optimum solution of WMS operation during Δt, expressed by:

- volumes in water reservoirs at the end of Δt;
- flows transported through the WMS;
- flows withdrawn, consumed and discharged by each water user, as average values on Δt (m^3/s);

The computer program **ALOC3** is written in TURBOPASCAL and is structured in two main parts:

- SUPERK routine for Out-of-Kilter algorithm;
- the main program itself with other four routines:

\- to read of the text file with non changing data which describe the arcs-nodes network and its parameters;
\- to input the data characteristic for the analysis time interval according to the menu;
\- to process the output data;
\- to make the results visible on the monitor.

This model was used for an application in Arges Basin.

B. Long term optimization modeling for strategic operating

Imprecise and non-commensurable objectives for reservoir operation are addressed through fuzzy dynamic programming in Fontane et al (1997). Fuzzy sets theory provides a mechanism to represent the degree of satisfaction of various objectives through the use of fuzzy membership function measures that can be combined in an integrated fashion.

The fuzzy optimization model was solved as a deterministic problem, but a lot of 200 possible realized annual series of inflows were considered. The results of fuzzy dynamic programming optimization yielded 200 possible realizations of optimal reservoir storage and reservoir release for each discrete state and each month. This information can be used to develop either storage or release decision rules. In this application a **neural network** was trained to **predict optimal ending storage** as a function of initial storage and forecasted monthly inflow.

The individual conventional reservoir uses are commonly described as functions of quantifiable targets for power, storage or release. The integration of multiple objectives often generates difficulties since the units of these objectives are not easily made commensurable on the same scale. Hence, assessment of operation is often conducted by comparison of actual releases, storage and power to specified targets imposed for each objective and assuming a direct correspondence between the degree of satisfaction of this objective and the respective departure of actual operation from the target value. Such assumptions are adopted in goal programming, for example. Compromise programming uses a metric of closeness to an ideal value for each operational objective. The metric is defined as ratio of the deviation of a specific solution from the ideal, to the maximum deviation between the ideal and the worst solution. This metric varies between 0 and 1, regardless of the units of individual objectives, while the degree of satisfaction varies as the power of the norm applied to the metric. However, these are mathematical hypotheses only, which are not derived from a direct analysis of how water managers and users perceive the satisfaction of an objective as a function of the actual operating characteristics of a reservoir. Under non-conventional objectives (like recreational benefits, habitat preservation etc.), this evaluation is more difficult. Interpreting the degree of satisfaction of such objectives as functions of variables that are affected by reservoir operation becomes a very subjective matter.

The fuzzy alternative for characterizing reservoir objectives is to simply use linguistic descriptors, such as “adequate” water supply, “satisfactory” power production, “suitable” fish habitat etc. The problem then is to interpret how the variables associated with an alternative reservoir operation satisfy these linguistically described objectives. The degree of satisfaction will depend on the experience and opinions of the water managers and users and on the constraints imposed on the system operation. In interpreting degree of satisfaction, water manager and various users consider and synthesize some issues as the perceived long and short term impacts of water shortage or surplus, the accuracy of available estimates of system state variables and demands, the resiliency of the system, the degree of risk aversion manifested by water users and managers. The concept of fuzzy sets and membership functions provides a way to materialize the qualitative judgments that are involved in evaluating alternative states of reservoir operation.

Fuzzy sets is a mathematical construct that is useful in addressing imprecise concepts by allowing a gradual transition from a situation that completely fulfills a concept to a situation that does not. In our problem, if we consider a state resulting from a given alternative strategy of reservoir operation, there is a vagueness or fuzziness associated with the membership of that strategy in the set of strategies that achieves a given reservoir objective. For example, the set of reservoir operations that achieve the objective O, stated using an imprecise linguistic description, may be modeled as a fuzzy set, having an associated membership function. This function takes values related with the reservoir state (storage level or volume, downstream flow rate or stage, power generated etc.) and transforms them into a value on the continuous interval 0-1. The value that membership function takes on indicates the membership grade or the extent to which an operational strategy is compatible with membership in the fuzzy set (or relative degree of satisfaction of the imprecise objective O).

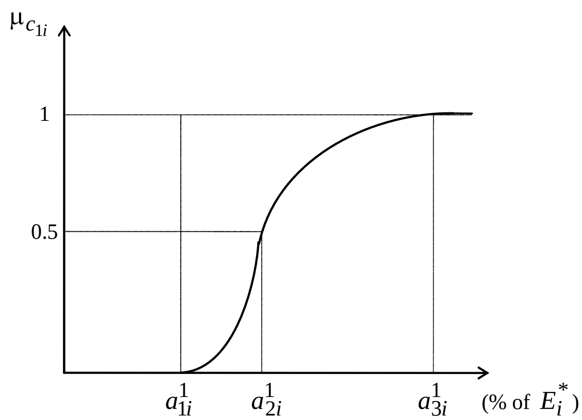
To obtain the membership functions for reservoir operation objectives, some actual field surveys of the involved representatives of water users must be derived. The city water system managers, reservoir managers, water resources planners, fish and wildlife experts etc. are to be interviewed to describe their interpretation of how well a state resulting from reservoir operation meets their own specified objectives. The responses are then fitted to suitable membership functions by least square method.
Because scheduling of reservoir operations is commonly formulated as a multistage decision – making problem, the dynamic programming is an appropriate solution technique. This technique seeks an optimal set of decisions (e. g. reservoir releases) over time intervals (stages) that results in states or outcomes (e. g. reservoir storage, energy production, downstream flows) that optimize a performance (or utility) function of the outcomes. In fuzzyfied form, the goals and/ or constraints can be specified by subjective, linguistic terms using the membership functions to express subjective perceptions related to the degree to which outcomes, resulting from alternative decisions, fulfill these fuzzy goals and/ or constraints.

In formulating the multi-objective operation problem for multi-yearly regulation reservoir, the stored volume to be obtained at the end of the year was considered as the fuzzy goal and the set of monthly water uses or objectives were accepted as the fuzzy constraints. However, for simplicity and input/ output data decreasing, only six bimonthly seasons were effectively used in numerical simulation.

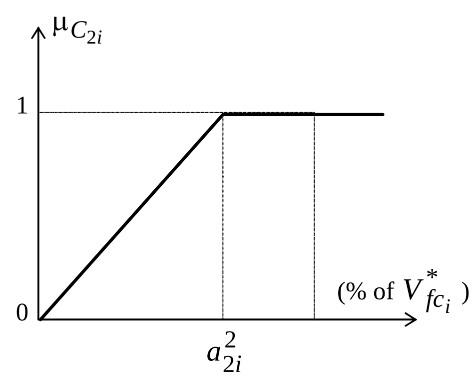
The fuzzy nature of the problem arises from the subjectivity associated with the prescription of the storage goal and in the definition of each constraint as a subjective or linguistically described attribute. In literal terms, the problem can be posed as follows: Obtain the fuzzy goal: ”stored volume at the end of December will be” *in the neighborhood* of a *secure value* “for the next two – three months with cold conditions and increased energy demands” (membership function μ_G) and satisfy the fuzzy constraints – figures 29:

1. *Adequate* hydropower generation (membership function – figure 29-1);
2. *Sufficient* flood control space (membership function- figure 29-2);
3. *Suitable* downstream fish habitat (membership function- figure 29-3);
4. *Enjoyable* landscape effect (membership function- figure 29-4).

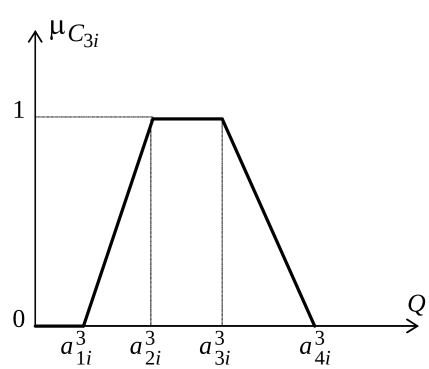
To derive the membership functions for the fuzzy goal and constraints, some representatives and experts of interested groups (power system engineers, flood control managers, environmental and wildlife experts, experienced recreational agencies etc.) are to be interviewed. Generally, the results of such interviews reveal that experts perceptions of the degree of satisfaction of a reservoir objective are influenced by the season of operation and hence the membership functions must be developed for different seasons of the year. For mathematical convenience the hypothetical responses are described using piecewise linear, trapezoidal and S- shaped membership functions – figures 29.



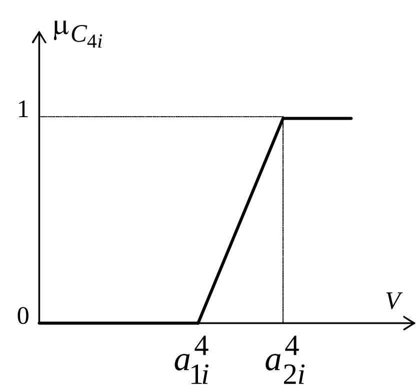
1. Fuzzy membership function for hydropower generation (as a percent of ideal production).



2. Fuzzy membership function for flood control (as a percent of imposed value).



3. Fuzzy membership function for fish habitat (as dependent on in-stream flow).



4. Fuzzy membership function for landscape effect (as dependent on volume in storage).

Figure 29. Membership functions function considered in the fuzzy model

These types of membership functions were accepted for illustrative purposes. In reality these may have more complex analytical expressions, but it remains as essential feature that each one reflects the particular perception of a specified water users group.

The general methodology described here is most effectively detailed in the context of a case study. An example application is that of the Izvorul Muntelui reservoir, the greatest reservoir on Romanian rivers.

This storage reservoir was constructed on the Bistrita River, upstream of an intense populated zone. It stores high native spring inflows from the river basin and regulates the long term outflows, having about 1,000 million cubic meters (Mcm) as useful storage volume for a multi-annual mean inflow of 42 cubic meters/ sec (cm/s). The reservoir must be operated to include conventional objectives of hydropower generation, flood control and water supply. Downstream releases through an on – peak hydroelectric plant of 210 MW installed power and 434 GWh/yr mean energy production, with major demands during the cold season. High flows used at this hydro-plant into the on – peak hours are then redressed by a downstream cascade of small reservoirs and off – peak hydropower plants. In the recent years, some non-conventional objectives appear to be more and more pressing for any reservoir operation. These objectives include catering to the needs of fish habitat and water quality downstream, meeting recreational demands for tourism, angling and nautical sports etc.

Membership grades for adequate hydropower generation were fitted with typical monotonically increasing S – shape function. This function indicates a domain of states (percent of ideal season energy production) associated with reservoir operation perceived to have non-membership in the objective fuzzy set, followed by a domain of states with growth in membership grade related to the given objective, and finally a domain of states that are perceived to have complete membership.
Membership grades for sufficient flood control space were assumed to vary linearly between 0 for no flood control volume, and 1 for an imposed (sure) value, according to season position within the year.
Membership grade for suitable downstream fish habitat takes on a uni-modal, approximately trapezoidal form.
Consequently, at each time step of the optimization time horizon, the intersection of the fuzzy constraints is defined, and dynamic programming is particularly well suited for solving optimization problems with objective functions defined by the fuzzy constraints combined with the fuzzy goal for December. The constrains are defined by Equation of the ending condition for backward dynamic programming analysis, being related to the degree of satisfaction for fuzzy goal; Equation describing water balance (continuity) for a certain season, and restrictions imposed on storage level and releases, respectively. If seasonal inflows are accepted as known, then this problem is a deterministic fuzzy dynamic programming model that may be solved in backward scheme.

In this particular application, the use of the proposed max – min stage return function did not perform well. The reason is that some of the reservoir objectives could not be satisfied at all in certain seasons for any combinations of reservoir storage. Therefore, if the value of their membership functions was zero, the stage return function also will be zero. Since the objective function is a max-min formulation, if any of the stage return functions are zero, the value of the objective function will also be zero. Practically then, the problem solution became completely dominated by the season where any fuzzy constraint could not be satisfied and the optimization becames meaningless, since all operational policies produced exactly the same value of the overall optimal return function at the initial stage. This situation does not occur with the maximum weighted sum formulation, since the membership function values of all objectives contribute to the stage return function. Hence, such type formulation will be used in numerical simulation for the large reservoir water management system.

To calculate the degree of satisfaction for hydropower generation, a maximum seasonal number of hours at on – peak operation, h_i^{peak}, was imposed.

In the example of Izvorul Muntelui Reservoir on the Bistrita River, for the lower initial storage of 650 Mcm, the mean annual degree of satisfaction for fuzzy constraints is only 55% and in compensation the fuzzy goal was 85% satisfied. The flood control is completing satisfactory during the year, but energy production is realized at 30% of annual ideal level, with complete un-satisfaction for the last season.

If initial storage is placed at favorable V_{end}^* value (850 Mcm), the mean annual degree of satisfaction for fuzzy constraints increases to 85%, with seasonal values varying between 76% and 95%. The cold seasons 1 and 6 are well covered by power generation (96% and 100% respectively), but for these season the downstream fish habitat constraint is rather unsatisfied. Fuzzy goal is now satisfied at only 77%, but all operational objectives are better supported by those defined as fuzzy constraints.

The two optimal solutions presented above prove that the fuzzy dynamic programming manages reservoir operation towards the favourable ending storage, V_{end}^*. Therefore, it may be supposed that any annual operating cycle will be started at a storage level in close proximity of this value.

Accepting such hypothesis, a **long-term analysis of reservoir operation** performance can be fulfilled. For this, a 400 years time – series of monthly inflows was synthetically generated by Thomas-Fiering forecasting model. The fuzzy dynamic programming model - **FDP Model** has the ability to incorporate some imprecise (subjective or linguistically described) objectives and to perform a long – term analysis of degree of satisfaction for various fuzzy goal and constraints using a lot of synthetically generated annual inflow sequences.

However, for system manager is most desirable to have a tool as decision support for current reservoir operation, with only short-term (monthly) sure forecasting on the inflow discharges. A standard operating policy (SOP) is defined for each reservoir at project stage, but rarely such a SOP intends optimization of available water management.

Including of multiple, conflicting and often imprecise operational objectives in the SOP definition is practically impossible.

That is the reason why the optimization models were more and more used to develop operating policies able to harmonize these objectives with random nature of hydrological processes.

The **DPN model** (Raman and Chandramouli, 1996) is an optimization model using a pattern recognition approach for a neural network to implement deterministic DP results as operating policy for reservoir operation, and called this solution. Introducing the fuzzy component to DPN model **FDPN Model** is detailed and resulted neural networks are then verified using recorded data. As optimization model it is accepted the fuzzy dynamic programming model (FDP Model). For each bimonthly season, a neural network (NN) having as input data initial storage and forecasted inflow and as output value the optimal ending storage, is to be derived. Such a NN must to be trained to predict an optimal response (seasonal ending storage) to the particular values of input information (seasonal initial storage and forecasted inflow). Training is carried out using some trained data sets, which are obtained by running FDP model with different annual scenarios of inflows data –912.

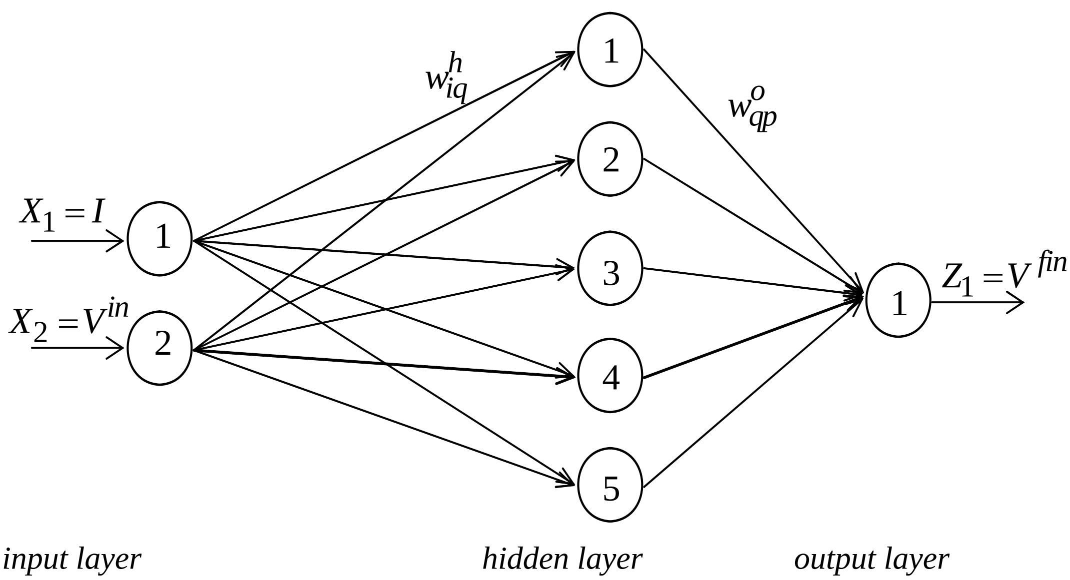
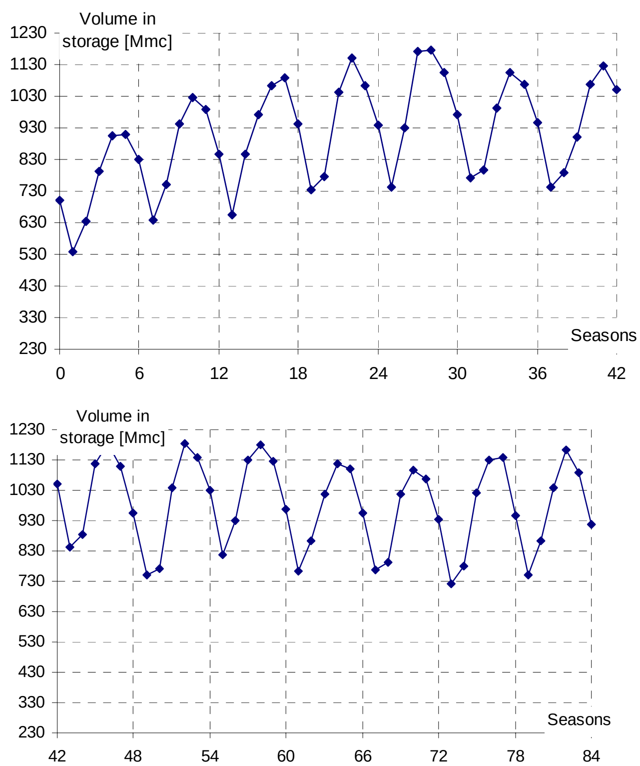


Figure 30. Neural network architecture.

The neurons in different layers are interconnected by means of weights; neurons in the input layer simply acts as a buffer, introducing the input data and the neurons in the hidden and output layers are active ones, processing the received information. The input to each neuron q in the hidden layer is the sum of the weighted input signals and this input is processed by a sigmoid activation function to produce the output signal of the *q*-the neuron. For all active neurons the same activation function was used. The output of neurons in the output layer (here only one, $p = 1$) is computed similarly, for the input signal. In this NN, the network output predicted optimal volume in storage at end of season.

Training is performed with back-propagation (BP) algorithm, by a supervised learning approach. The network is successively presented with a set of input-output patterns obtained from FDP running. For each pattern, the learning BP algorithm updates the interconnection weights by the steepest gradient descent procedure to find minimum difference between the desired (known) response and the output response from NN.
As application an example was provided, a simulation of Izvorul Muntelui reservoir operation with NN operating policy during 1966-2000 was provided (First report of UTCB team).

The most suggestive illustration of NN performance for reservoir operation is shown in Figure 31 where the storage variation versus time is represented. Although the limit values $V^{\min}$ and $V^{\max}$ were imposed very larges (230 to 1,230 Mcm), the NN – operating policy manager operation towards the upper zone (greater hydropower efficiency, more enjoyable landscape effect). In only 7 seasons the ending volume in storage was below 600 Mcm, with a minimum value of 437 Mcm in the first season of 1988. The greatest values of volume in storage appear in the 4 th season (1202 Mcm/ 1981, 1184 Mcm/ 1973, 1174 Mcm/ 1970), but still allowing some degree of satisfaction for flood control space (57%, 95% and 100% respectively).



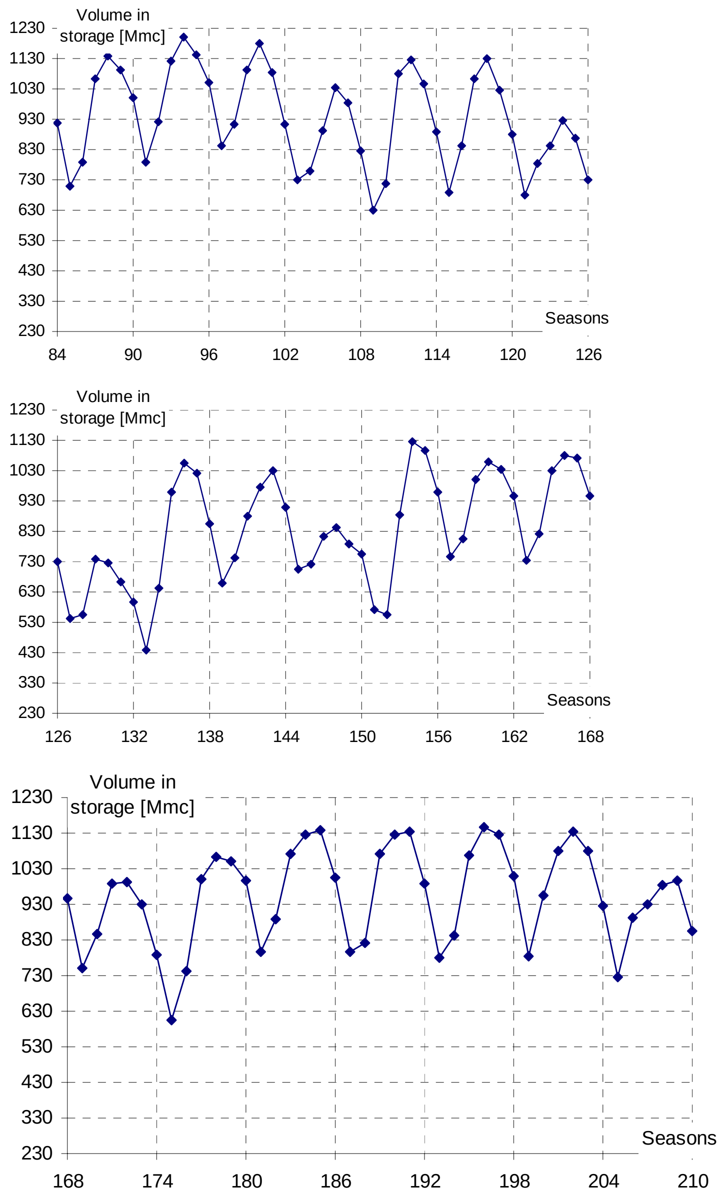


Figure 31. Volume in storage versus time variation on the simulation interval 1966-2000

The model is used at the hydro-energetic dispatch of Bistrita River. The application could not be considered for ANAR, because it is specific only for the inter-years regulation reservoirs, specific to hydropower production. In this case the input/output data are given by Hydroelectica Enterprises Company.

C. Short term, tactical operating modeling of a complex cascade of reservoirs

In case of a complex cascade of reservoirs, associated with hydropower energy production – Figure 32, the daily analysis needs to be provided; the interval time in analyzing the water balance can be from 1 to 3 hours. There are very limited cases when the travel time between two reservoirs is less then 3 hours (Arges Basin is one of this exceptions). The general model for optimization will take into account 3 hours leg time.

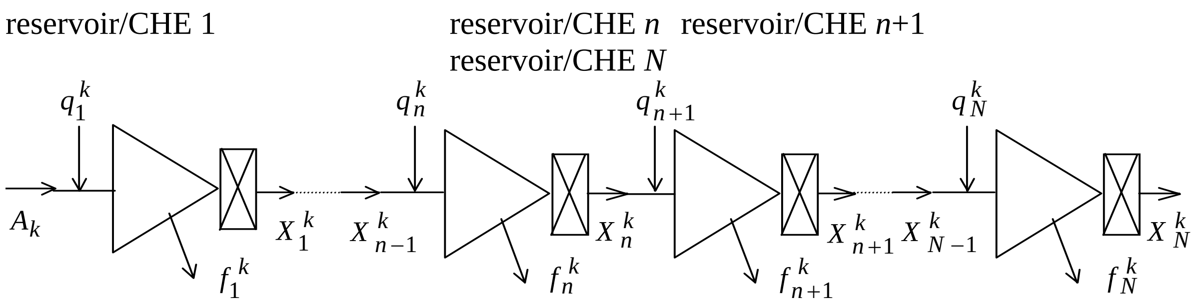


Figure 32. Reservoirs cascade and inputs-outputs volumes considered in water balance equation

The optimization model **ACS** (Radu Popa, 2004) is based on the annealing algorithm, addressed to the water balance equation solved taking into account different constraints like:

- volume variation in each lake need to be in a pre-definite interval;
- the initial volumes are known from the monitoring activity;
- final volumes variation interval could be defined to be less then the initial considered one (for the initial volumes): volume corresponding to the minimum energetic water level and the volume corresponding to the normal retention water level;
- the velocity of discharging/filling the volumes of a reservoir needs to be less then a safety determined one
- the stokes of diffluent volumes (where the total volumes are considered as energetic volumes and other discharged volumes for other use) in the cascade cannot be negative after a day of operating the reservoirs
- the energetic volumes can be restricted too, for different conditions of energy production;
- the ecological discharges need to be assure downstream of each reservoir in the cascade.

As decisional variables are considered the total diffluent volumes and the objective functions are:

- the diffluent non-energetic discharges to be minimized;
- the energy production to be as near as possible of the energetic dispatch and in conformity with the user demands;

- hydropower production to be maximized in accord with a dispatch graphic demands.

ACS Model needs to get an initial solution to begin the optimization procedure. The annealing algorithm offers a probability for the identified solution of optimization. It doesn't guarantee the optimal global solution for the optimization problem, but offers some satisfied sub-optimal solutions for the complex nonlinear problems. This model was applied for a cascade of 27 serial and parallel reservoirs and Hydrotechnical power production units – Olt Basin – with good results.

D. Reservoir optimal policy for flood management

(i) One reservoir with a certain class number for outflow devices

Normally, the flood storage volume is not enough large for flood control, so special discharge rules for the spillways during floods have to be established. The active interval for each type of spillway is normally found by a trial and error procedure, which is still hard and time consuming. To avoid these difficulties, an optimal control model is established in order to automatically obtain the spillways optimal operation rules during floods.

The purpose of this dynamic optimization model is to obtain the operation rules for the outflow devices during flood periods, in order to get downstream outflows as reduced as possible.

The classical equation of water balance needs to take into account a certain class number for the outflow devices; the spillways are differentiated not only by their structural characteristics, but also functionally, the same constructive type of outflow device having the possibility to belong to different equivalence classes; the discharge evacuated by each working device from different classes as well as the state variable of outflow devices from the considered class and level, were considered. If spillways are not working the defined function is considered 0.

Taking into account the active interval for each flood spillways these are classified into the following two categories:

a) first type spillways (figure 33): at $H_j^{'}$ level, the gates are opened, in the order to allow water evacuation, while at $H_j^{''}$ level (lower, equal or greater in comparison with $H_j^{'}$), the gates are closed; the maximum level of water always exceeds $H_j^{''}$;

b) second type spillways (figure 34): the meaning of $H_j^{'}$ and $H_j^{''}$ is the same, but it is not allowed to exceed the $H_j^{''}$ value, which is the maximum level in the reservoir.

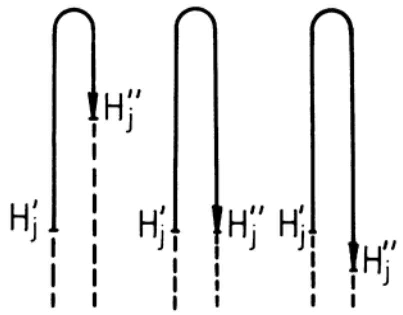


Figure 33. First type spillways.

Figure 34. Second type spillways.

Taking into account each class of spillways, the water balance equation takes a discrete form which allows by successive iterations to generate the volumes, the downstream discharges and the levels in the reservoir. Further on the optimal control model for spillways operation rules is applied, taking into account that the downstream hydrograph must be almost rectangular, the maximum flow value not exceeding, if possible, the discharge value q_{adm}, which can be transported by the river without causing floods. On the other hand, it is desirable that the flood wave should be transited through the reservoir as soon as possible, so the downstream flows must be as close as possible to the q_{adm} value; the objective function is defined applying this two objectives.

The following constraints are added:

- the height of the water over spillway crest, h_{adm} will not overpass its maximal value ($h_{adm} > 0$);
- two successive outflow values must be as close as possible to avoid quick variation of the downstream flows.

In these conditions, the unknowns of the model are the 2 *n* decision variables, representing the lower and the upper water level limits of functioning for each class of spillway devices.

In order to test the model, it was examined its ability to provide the adequate operation rules for the Belci reservoir (Romania), collapsed during an exceptional flood in 1991.

The conclusion of this application is that the presented optimal control model allows obtaining the operation rules of the outflow devices. Their use is very convenient for the operation staff of the dam.

During the floods, the decisions about the functioning of each outflow device are taken accordingly to the water level in the reservoir; this state variable is perfectly accessible, presenting a reduced risk of human errors.

(ii) Reservoir/polder optimal operating for flood management

The model was also successfully applied in case of complicated hydro-technical infrastructures as reservoir-polder systems. In this case the storage capacity is divided into two compartments by a longitudinal dam, as follows:
a) First part of the reservoir -permanent storage;
b) Second part is a polder (temporary reservoir).

The performed simulations in case of Vacaresti system showed the importance of a temporary reservoir, coupled with the permanent reservoir, by using adequate operation rules (opening or closing the discharging installations under a very strict control concerning the time of operation and the operational succession). The decision of flooding the polder must be taken in function of a properly chosen value of the inflow hydrograph discharge; this threshold value is obtained by a trial and error procedure, taking into consideration the constrains of the problem: the most reduced value of an almost rectangular shape of the downstream flood wave and the limits of the maximum water level in both compartments. The operation rules must include also some prescriptions to assure in the final stage of operation a water level in the permanent reservoir as close as possible to the initial level and a minimum level in the temporary reservoir.

(iii) Model of coordinated control for the reservoirs

In the river basins with hydraulic structures, there is a close connection between the hydrological forecasting and reservoir control. Therefore, on account of flood wave forecasting the optimum way for reservoir control is established, i.e. the reservoir outflow hydrographs are required for hydrological forecasting downstream the reservoirs.

For the flood wave attenuation and control through the reservoirs, the coordinated operation is used which is based on a certain classification of reservoirs into types and defining for each type, the sets of outflow hydrographs that should satisfy certain objectives and meet the operation restrictions.

From the standpoint of their operation under floods, the reservoirs are devided into two types:

- Reservoirs of type I, whose outlets lack gates to allow a total adjustment of the outflow discharges (Vidraru, Paltinu, Rausor). Within these reservoirs only a partial adjustment can be performed on the outflows through the operation of bottom outlets and of the turbines. Therefore the flood waves thus routed through the reservoir undergo an “uncontrolled attenuation” (figure 35 a);
- Reservoirs of type II, whose outlets are operated by gates which allow a total adjustment of the outflow discharges (Budeasa, Golesti, Ramnicu Valcea), i.e. a “controlled attenuation” of the flood waves (figure 35 c). If the maximum operation level (NME) is higher than the upper part of the gate it is impossible to provide a totally controlled attenuation up the NME considering the fact that once the upper limit of the retention gate is exceeded, certain operations have to be performed (lowering the clack

weirs, for instance) which make it impossible to entire control the outflow discharge. In this case, the flood waves undergo a “partially controlled attenuation” (figure 35 b).

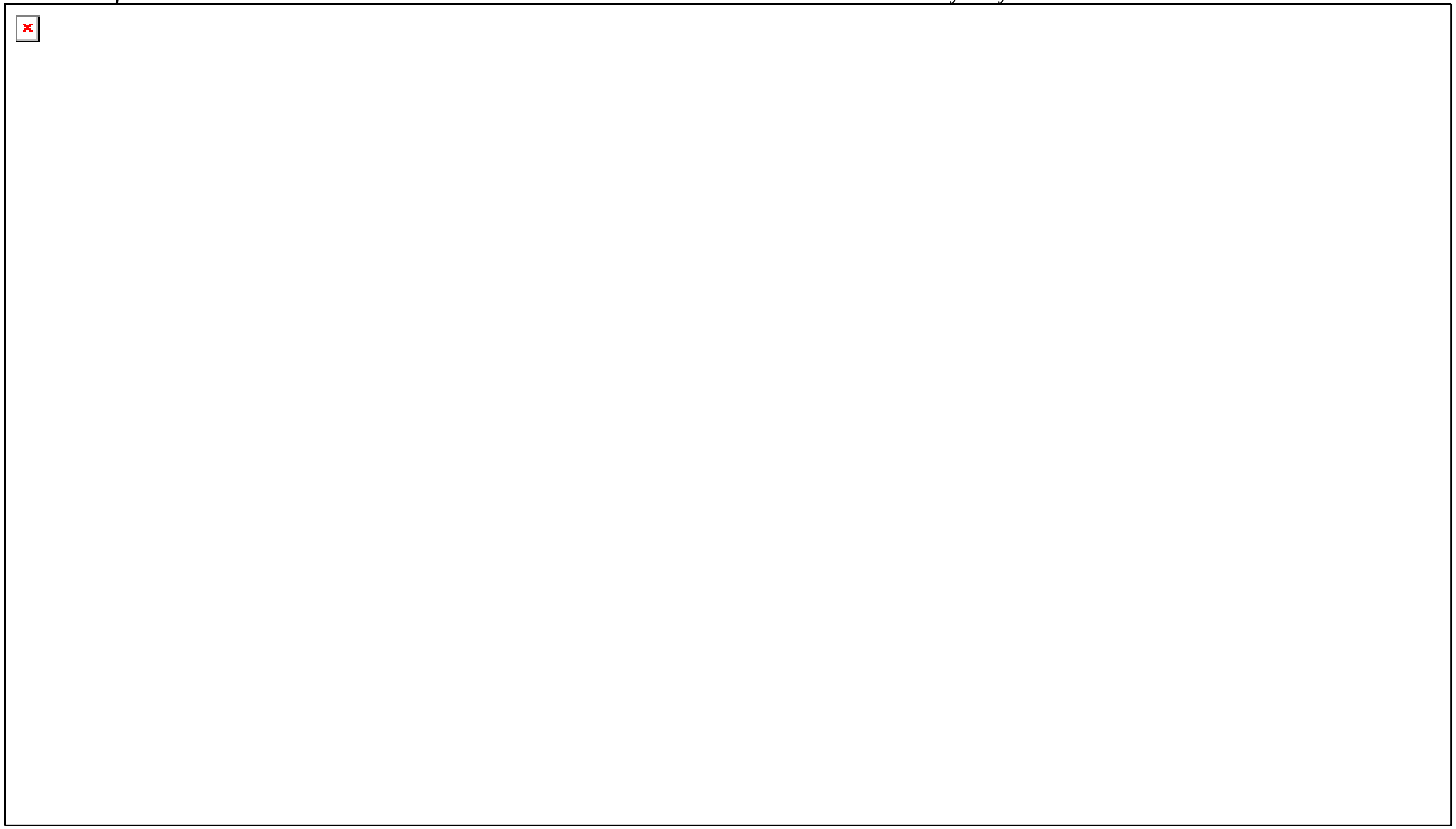


Figure 35. Draft schemes for flood-wave attenuation in a reservoir

The analysis of the data referring to the method that certain existing reservoirs operate, has resulted in a certain outlook on the standard reservoir running on account of which a set of hydrograph types are defined (a set of operation policies - SPE).

The following issues are taken into account at the SPE establishment:
a) the type of reservoir;
b) the operation restrictions, conditioned as follows:

$$NmE \le H \le NME$$
$$H \le NMA \le NME$$
$$\frac{\Delta H}{\Delta t} \le G_d$$
$$Q_d \le Q_{in}$$
$$Q_d \le Q_{dc}\ ,$$

where:
NmE is the minimum level for reservoir operation;
NME - the maximum level for reservoir operation;
NMA - the maximum admissible level which should not be exceeded for certain reasons such as flooding over economic objectives situated at the reservoir inlet area;
$\frac{\Delta H}{\Delta t}$, the increase or decrease gradient, for the reservoir water level, which should be smaller than a given G_d gradient, which is required by the structure design according to the technical solutions approached in construction, the material used, etc.
Q_{in} - the flooding discharge of the downstream reservoir zone;
Q_{dc} - the maximum capacity of the outlets at a given level;
c) the objectives of the reservoir operation: obtaining larger power productions; providing the required amounts of water for various uses; reducing the damages caused by floods and the damages of sediments in the reservoir;
d) the use of the entire flood control capacity;
e) the way of flood wave formation and composition within the river basin;
f) the level in the reservoir after flood, should tend towards the level of normal retention considering the possibility of successive flood occurrence.

In case of type I reservoirs, the SPE contains only several control versions, defined by progressive entrance in function of the turbines and the bottom outlets. Therefore, the control policy 1 (PE-1) is given by an uncontrolled attenuation - overflow, considering that the turbines and bottom outlet weirs are shut down. In case PE-2, a turbine is functioning (more or all ones depending on circumstances), and in case PE-3, a bottom outlet should be firstly open and followed by the other ones, until all outlets are completely opened.

The deriving of outflow hydrographs for each control policy is done using Puls method. The method relies on the continuity equation written with finite differences.

The following elements are needed to compute the attenuation of flood wave in a reservoir:
- the inflow hydrograph into the reservoir as a string of values in the period of time;
- the curve of reservoir capacity;
- the rating curves of the outlets for reservoir. Its depend on water level in reservoir as well as on the hypotheses of functioning for outlets.

In case of "uncontrolled attenuation", the SPE has contained especially the following control rules (see figure 35 c): "peak cutting", "rectangle - transformation", "retaining - cutting"; " retaining over T_1", "routing - retaining", "routing over T_1", "pre-emptying with an imposed discharge", "retaining up to a given water level" and "pre-emptying - routing - retaining".

All these control rules (excepting the last one) are recommended to be used in case when the maximum discharge of inflow flood is greater than flooding discharge. In opposition to this case, the washing out the sediments from the reservoir may be done using the "pre-emptying - routing - retaining" rule (figure 35 c). First, the reservoir will be pre-emptying with a discharge smaller than flood maximum discharge until a water level close to the minimum exploitation level will be reached, then the flood peak will be route with increased velocity. This action will move and transport the sediments downstream. Second, the gates are closed, for assuring the reservoir replenishing - to retain into the reservoir the volume of decreasing curve of the flood, which is less loaded with sediments than the water volume, which has already passed on.

A "partial control attenuation" should be done for type II - reservoirs, in case of very high floods. The SPE in such a case is similar to the SPE for "controlled attenuation". For instance, the "peak cutting" rule is shown in figure 35 b. The methodology to use this rule is detailed considering as an example Valcele reservoir, (the Arges river), which has an outlet with one gate and 3 bottom outlets. It is mentioned that the upper part of the gate is under NME and it has only two functioning positions: close and complete open.

The "peak cutting" control rule (figure 35 b), supposes for the start, an adequate operation of the 3 bottom outlets for assuring the routing through reservoir of inflow flood until the time t_1. Operating the bottom outlets in the period t_1, t_2 does the cutting off the flood peak, then the gate is opened completely achieving an uncontrolled attenuation. The time t_1 and t_2 are determined as though the cutting discharge Q_r would be as close as possible to maximum outflow discharge Q_{md} derived on the "uncontrolled" part of the hydrograph.

The "partial - controlled" attenuation is assigned mainly when the cutting discharge Q_r (figure 35 c1) - derived in the case when water level in the reservoir reaches the upper part of the gate - is greater than flooding discharge Q_{in}.

The following hypothesis are given: the rain is uniformly distributed within the basin; the initial water level in the reservoir is NRN (normal retention level); between the objective O which must be protected and the last reservoir there is no major tributary. In this case, the reservoirs shown in figure 2 a,b will be controlled using the "rectangle - transformation" rule (figure 1 c2,c1) which will assure minimum discharges close to the objective or the "peak cutting" rule when the pre-emptying assigned by the previous rule is not allowed.

Case of the scheme shown in the figure 36 c:

- Reservoir 1 will be controlled by one of the following rules:
- "retaining - cutting";
- "retaining over T_1" or "retaining up to a given water level" (figure 35 c3).
- Reservoir 2 will be controlled by one of the following rules:
- "routing - retaining";
- "routing over T_1";
- "pre-emptying with an imposed discharge" (figure 35 c4, c5) for assuring favorable composing of flood waves, by moving forward one of the outflow hydrograph's peaks to create a difference between the reservoirs working in parallel.

Case of the scheme shown in the figure 36 d:

- Reservoirs 1 and 3 will be controlled by one of the following rules:
- "routing - retaining";
- "routing - retaining over T_1";
- "pre-emptying with an imposed discharge".
- Reservoir 2 will be controlled by one of the following rules:
- "routing - retaining";
- "routing - retaining over T_1";
- "routing - retaining up to a given water level".

If the rain is not uniformly distributed within the river basin - heavy rain upstream reservoir 2 (figure 36 d) the operating would be done, for instance, in the following way: reservoirs 2 and 3 using the "routing - retaining" rule and reservoir 1 using the "retaining - peak cutting" rule.

The control scenario (SE) is made up by the optimum control rules of the reservoirs within the water management system corresponding to a certain way of flood formation within the river basin. 10-15 apriori SE within a river basin may be set up using the ***VIDRA model***.
First, the extraordinary floods occurred within the river basin will be analyzed aiming at setting up the SE. The simulation with VIDRA model will show the routing of flood through the reservoirs within the river basin, having as result the optimum outflow hydrographs for each flood.
Second, taking into account the mentioned analysis for recorded floods, other ways of flood formation will be invented within the river basin. These are characterized by heavy rain downstream and upstream of the reservoir; velocity and moving direction of the precipitation and the duration and rain intensity.

The hydrographs of discharges will be generated with VIDRA model corresponding to each way of flood formation and the model will show the flood routing through the reservoirs, having as result the optimum policy for reservoir operation.

The simulations done with VIDRA model are useful for ascertaining the relationship between the way of flood formation within the river basin and the optimum operating rules for reservoirs (SPE) previous-defined.

Several usual schemes of high water management will be analyzed to highlight the above-mentioned relationship (Figure 36).

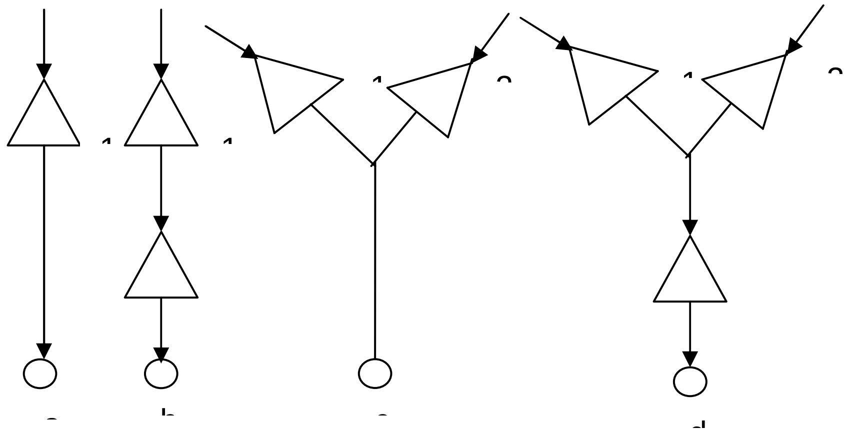


Figure 36. Types of schemes for water management:
a – scheme with remote reservoir; b – scheme with reservoir in series; c – scheme with reservoirs in parallel; d – complex scheme with different types of reservoirs

The following hypothesis are given: the rain is uniformly distributed within the basin; the initial water level in the reservoir is NRN (normal retention level); between the objective O which must be protected and the last reservoir there is no major tributary. In this case, the reservoirs shown in figure 36 a,b will be controlled using the “rectangle - transformation” rule (figure 35 c2,c1) which will assure minimum discharges close to the objective or the “peak cutting” rule when the pre-emptying assigned by the previous rule is not allowed.

Case of the scheme shown in the figure 36 c:

- Reservoir 1 will be controlled by one of the following rules:
- “retaining - cutting”;
- “retaining over T_1” or “retaining up to a given water level” (figure 35 c3).
- Reservoir 2 will be controlled by one of the following rules:
- “routing - retaining”;
- “routing over T_1”;
- “pre-emptying with an imposed discharge” (figure 35 c4, c5) for assuring favorable composing of flood waves, by moving forward one of the outflow hydrograph’s peaks to create a difference between the reservoirs working in parallel.

Case of the scheme shown in the figure 36 d:

- Reservoirs 1 and 3 will be controlled by one of the following rules:
- “routing - retaining”;
- “routing - retaining over T_1”;
- “pre-emptying with an imposed discharge”.
- Reservoir 2 will be controlled by one of the following rules:
- “routing - retaining”;
- “routing - retaining over T_1”;
- “routing - retaining up to a given water level”.

If the rain is not uniformly distributed within the river basin - heavy rain upstream reservoir 2 (figure 36 d) the operating would be done, for instance, in the following way: reservoirs 2 and 3 using the “routing - retaining” rule and reservoir 1 using the “retaining - peak cutting” rule.

In case a flood occurs, on account of the inflow hydrographs of the reservoir and also considering the initial stage of the reservoirs, the exploitation policies will be automatically selected from the set of operation policies (SPE) existing in the computer memory. The selection of the ***optimum version*** will be such that the following objective function (FO) should be minimum: $FO = \min\left[\sum_k \beta_k Q_{mk}\right]$ where:

Q_{mk} is the maximum discharge of the hydrograph at objective k; β_k are the weighting coefficients in the view of considering the relative importance of the objectives to be protected against floods.
The reservoirs within the ***Arges river basin***, which have a major impact on flood waves are: Vidraru, Zigoneni, Valcele, Budeasa, Rausor, Maracineni and Golesti. This partially developed application will be taken into account for the pilot basin.

*
* *

There is usually a perception that a multipurpose project is able to satisfy all objectives with a comparable degree of reliability. This is not necessarily true, as the above long term analysis so vividly demonstrates. The conflicting nature of hydropower generation and downstream fish habitat objectives is the most obvious one. Although the mean annual degree of satisfaction seems to be acceptable for hydropower generation (85.5%) and landscape effect (80%), some risk – averse water users and managers would find these results as unfavorable, because the 10-th percentile values of predicted degree of satisfaction (DS_{90}) are quite low (about 50% satisfaction at annual level, but with high seasonal variations). But the important fact is the description of the best water management solutions inside different types of reservoirs and the adversary effects in using or building such types of infrastructures.

V. ANAR Dispatch Interface as support of the decision process

The **Dispatch Application** (Dispecer Ape) now running under ANAR, is a distributed client-server application, based on the operational environmental data tree-like flow from level 4 to level 1.
The application was designed to cover 2 main functions:

1. Data flow & operational messages/reports surveillance & control
- Data flow consists of hydrologic, reservoirs and water quality observations – figure 37;
- Operational messages/reports consist of ‘system status’ reports (covering meteo, hydro, hydro-technical constructions, water supply, water quality, informational system, operations statements), explicit warnings/alarms, events, reports on floods effect, damages, etc – figure 38;

2. Framework for specific applications (reservoir operations, hydrologic & water quality monitoring & forecasting) and studies.

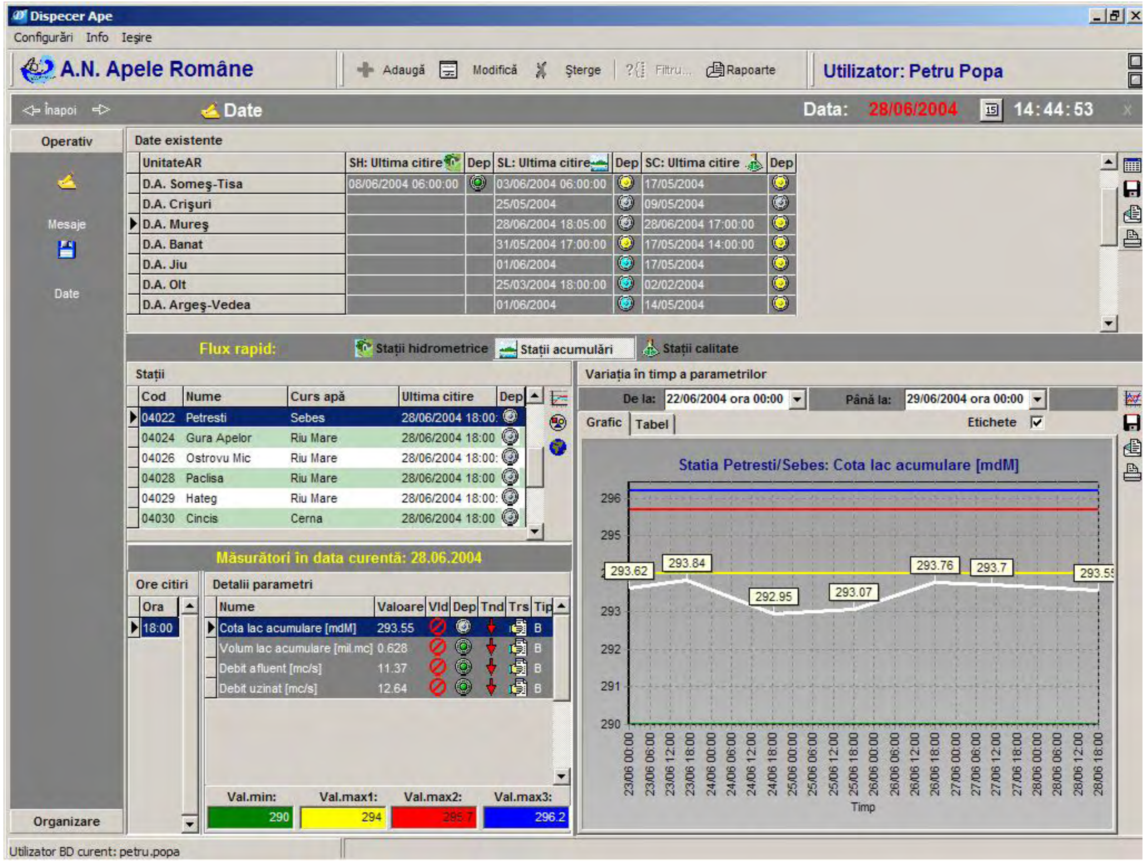


Figure 37. Interface for data collection

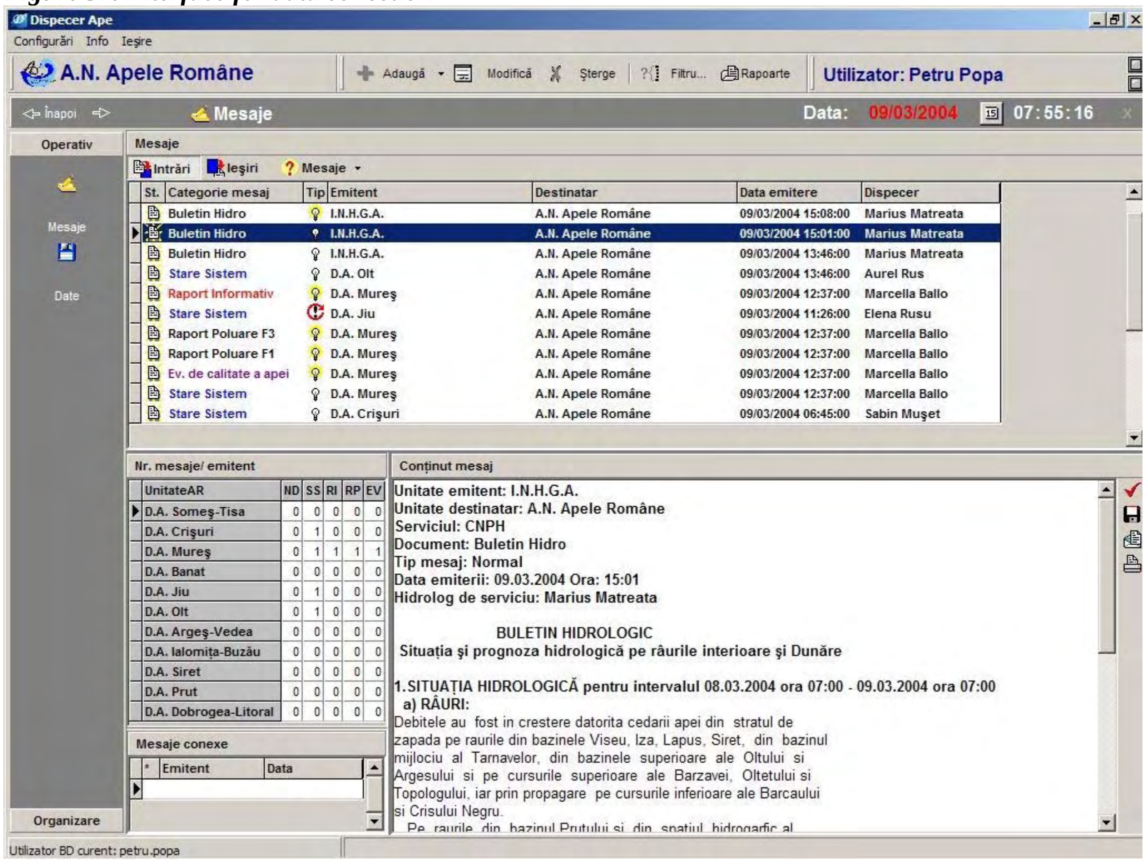


Figure 38. Interface for operational messages and information

Designed and developed under MS SQL Server platform, Dispecer Ape is also a data-pumping system, based on data replication feature of the servers. Information is routed through this system, up and down the tree, in order to answer to specific needs – Figure 39.

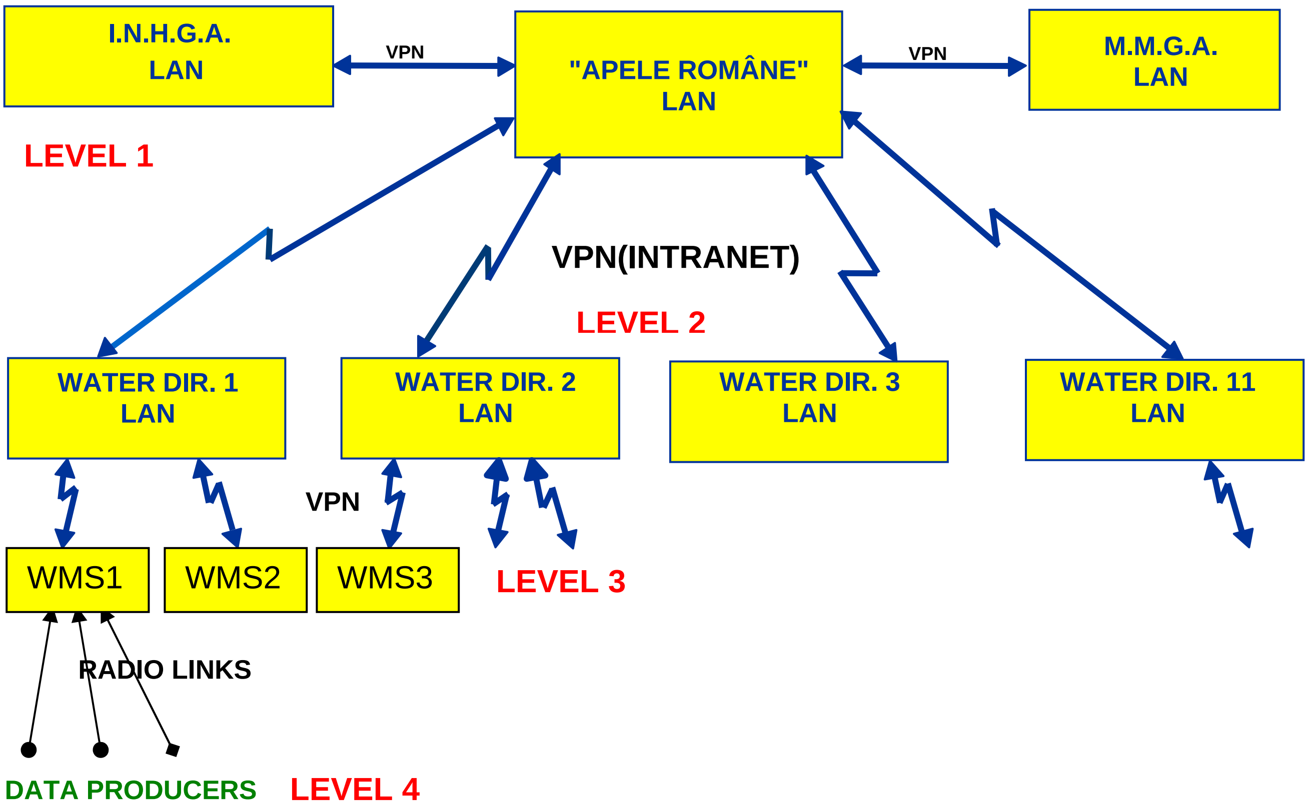


Figure 39. Hydro-meteorological and water management data informational system

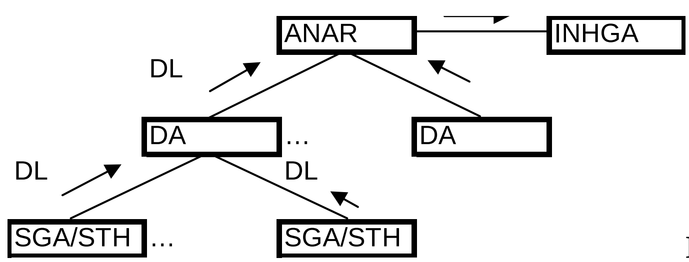
Water Dispatch makes use of the National Cadastre of Waters database and it surveys the data produced in time by objects inside this database.

Data table has this structure (all data is inside one table)

Field name	**Description**	**Format**
ID Data Measured	Unique identifier of the measurement	Unique identifier
ID Data Producer	Unique identifier of the object (sensor, etc) that produced the data	Unique identifier
CNP Originator	0 if data entered automatically or the social security number of the data-entry technician	decimal
ID Instrument	ID of the instrument the data was measured (to be implemented)	int
Data Read	Data and time of the	Small date time

	observation	
ID Parameters	Make a connection with the table “Parameters” and specify the ID of the state that is measured	Int
ID Tip Data	Indicator of data type: ‘B’ = rough data, ‘C’ = corrected, ‘P’ = forecasted, ‘S’ = simulated	char(1)
Val Parameters	Value of the observation, stored as a character, as the observation can be numeric, text, date and time	Var char(4000)
Validated	Indicator of whether the observation has been validated: 0=validated, 1=not validated	Tiny int

Data acquisition follows this sense inside the network – Figure 40.



Legend:
SGA=Water Management System (WMS)
STH=Hydrological Station (HS)
DA=Water Directorate

Figure 40. Data flux

After being validated and processed, forecasted data follow the inverse sense in order to reach level 3 offices – Figure 41.

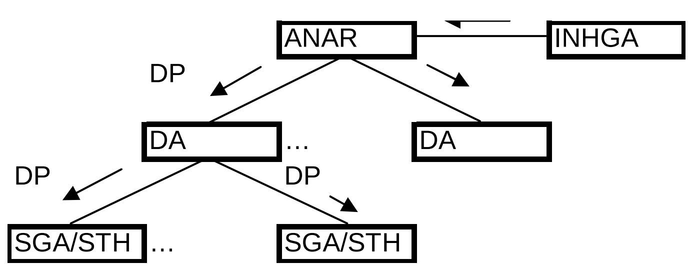


Figure 41. Validated data flux and output of forecasting models

National informational network consists of 41 WMS/58HS, 11 WD, ANAR HQ, INHWM and MEWM.

Legend:
Yellow: Water Management System (WMS), Hydrological Stations (HS), Level 3
Red: Water Directorates (WD), Level2

Figure 42. Regional collection points

As currently designed and deployed, the WATMAN DSS will rely on the existing Apele Române *Water Dispatch*—a display and reporting system developed by local IT specialists.

Interfacing with Water Dispatch

Being developed as a client-server application, data used and processed by other applications can be put/get in/from the same database in the same data format (recommended, see above). According to new types of data produced, new dedicated screens can be designed to act as frames in the Dispecer Ape framework.

CONCLUSIONS

Few DSS packages were presented including models developed for different specific applications: flood management, diffuse pollution control, water management in the Danube Delta River. Some specific optimization models for short term water allocation optimization, for long term planning and for flood management in different types of reservoirs.

Using all these information, as well as the international concepts for DSS and different other models for water management, will go further in designing the specific DSS applications integrated under the dispatch interfaces and at the level of the ANAR data base structure (for inputs and outputs). Some models would be of much help solving different aspects of optimization of water allocation during floods and for water supply.

The next part of this technical Report will be dedicated to this issue – proposal for a Romanian DSS Application.

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